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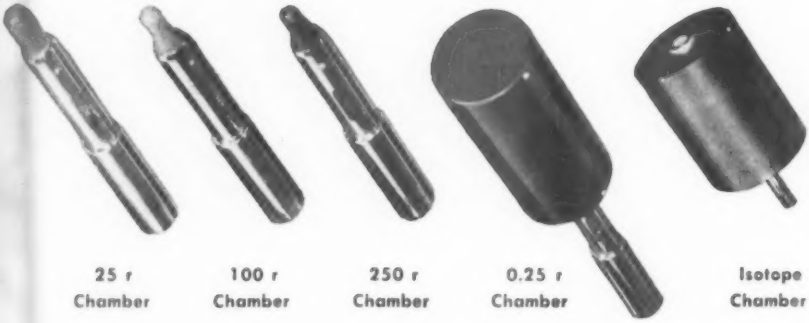

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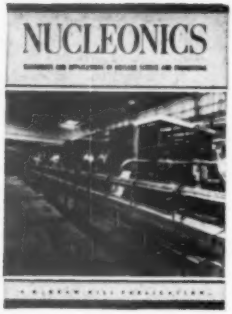

THE COVER shows the linear electron accelerator under construction at Stanford University. On completion, the machine is expected to be 200 ft long and to produce 1-Bev electrons. The 80-ft section shown has already been operated to produce 180-Mev electrons. Each 10-ft section is powered by a klystron that delivers a peak of about 10 megawatts.

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NUCLEONICS

An Annual Nucleonics Meeting

The scope of scientific research is continually broadening. This is true for the individual branches of science and for science as a whole. The best evidence of this growth is the number of scientific papers being published. In the past five years, for example, the annual number of pages which the *Physical Review* publishes has doubled.

As each branch of science broadens, the work of the individual scientist gets narrower until the point is reached where workers in one branch lose touch with those in the others. Therefore, when something of common interest develops, the need is felt for a common medium of information exchange, whether it be via the written word or the spoken word.

In the nucleonics field, there is such a common interest—*radiation*. It is being studied and used by physicists, chemists, biologists, engineers, etc. Among other things, the physicist is interested in the nature of radiation, the chemist in chemical changes caused by radiation, the biologist in how radiation affects the blood, and the engineer in how an industrial process can be controlled by radiation. Because of this interrelationship, it quite frequently happens that information developed by one group will be of interest to another —particularly in the case of such things as techniques and instrumentation.

NUCLEONICS was set up to meet this need, to serve as a forum in print for all people working with radiation. Now it appears a live forum is needed.

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NUCLEONICS (with which is consolidated "Atomic Power" and "Atomic Engineering"), June, 1951, Vol. 8, No. 6. Publication Office: 212 East York St., York, Pa.; Editorial and Circulation Offices: 330 W. 42nd Street New York 18, N. Y. Published monthly by McGraw-Hill Publishing Company, Inc. Entered as second class matter December 17, 1947, in the Post Office at York Pa., under the act of March 3, 1879. Copyright 1951 by McGraw Hill Publishing Company, Inc. All rights reserved. Curtis W. McGraw, President; Willard Chevalier, Executive Vice President; Joseph A. Gerardi, Vice President and Treasurer; John J. Cooke, Secretary; Paul Montgomery, Senior Vice President, Publications Division; Ralph B. Smith, Editorial Director; Nelson Bond, Vice President and Director of Advertising; J. E. Blackburn, Jr., Vice President and Director of Circulation. Allow at least ten days for change of address. All communications about subscriptions should be addressed to Director of Circulation, 330 West 42nd Street, New York 18, N. Y. Price per copy $0.75. Subscription rates: United States and U.S. Possessions $8 for 1 year, $12 for 2 years, $16 for 3 years. Canada, $10 for 1 year, $16 for 2 years, $20 for 3 years. Latin America, $15 a year. All other countries, $20 a year.

The best evidence of this is a random selection of papers which have been presented within recent months at meetings of a number of different societies: "On the Localization of Positron-Emitting Isotopes in the Human Body," before the American Physical Society; "Techniques in the Preparation of Radioactive Glass Beads" (which are used for biological and medical purposes), before the American Chemical Society; "The Effects of Radiation on Some Chemical Compounds," before the American Association for the Advancement of Science; and "Problems in the Establishment of Maximum Permissible Radiation Exposure Levels," also before the AAAS.

These papers and many others, presented at national and local meetings of a large number of societies, are of interest to more than just the membership of the particular society before which the paper is presented. For example, in the case of the first paper listed above, we were present when it was given and feel sure that both speaker and audience would have benefited if potential users (doctors) of the technique described had been present and had contributed to the discussion. Instead the audience consisted primarily of those interested in the physics of the method.

The British, who are quite alert to the informational needs of their scientific community, have already indicated an awareness of the need mentioned here. They have just announced (see p. 47) what promises to be the largest international conference on the beneficial uses of atomic energy which has yet been

(Continued on page 58)

Random Notes

• ***Questions** most frequently asked of us by prospective authors are: (1) In what form shall I submit a manuscript? and (2) What happens to a manuscript I submit after it reaches your office?*

The first question is easy to answer. In reply, we merely send the inquirer a four-page reprint which contains a list of detailed "Suggestions for Contributors," along with a description of our editorial policies and scope. Copies of this reprint are available for the asking.

The second question is not difficult to answer but it requires a bit more time and some philosophizing. When a manuscript is received in our office it is immediately acknowledged. Then the decision is made as to whether or not the subject matter of the paper falls within our editorial scope. Many articles are rejected at this point.

If the subject matter is of interest, the manuscript is passed on to one of the technical editors on our staff. One of four decisions must be made: (1) accept as is, (2) return for revision, (3) send to an outside reviewer, or (4) reject. (1), (2) and (4) are self-explanatory. In the case of (3), we have outside re-

(Continued on page 58)

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GENERAL ELECTRIC

Slow-Neutron Detection by Foils—I*

A method is described for measurement of slow-neutron densities by inducing activity in indium foils. The effects of fast neutrons, elimination of undesired activities, and adjustment of sensitivity, are among the factors discussed

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THE ACTIVATION METHOD for measuring thermal and epithermal neutron distributions is convenient when a sensitive, compact detector is required. It has been used by many investigators.

Sometimes, however, it is not recognized that two important corrections must ordinarily be applied to the experimental data. These are: (a) a correction for the absorption and scattering of the epithermal or resonance neutrons by the cadmium frequently employed to screen out thermal neutrons; and (b) a correction for the depression of the thermal-neutron flux by the detector. The latter is a diffusion phenomenon caused by the detector's acting as a sink for neutrons.

In the absence of the detector, a neutron crossing the proposed detector position has a certain chance of returning to the same spot and bolstering the neutron density, whereas, in the presence of the detector, neutrons are absorbed to some extent on crossing the detector and therefore have less chance of contributing to the neutron density at the detector site. Thus the detector lies in its own shadow, so to speak Bothe (*1*) has used the apt descriptive term "self-shading effect" to describe the phenomenon. It is also sometimes referred to as "foil drain."

These two corrections will be discussed next month in Part II of this two-part article.

The Method

The activation method of neutron detection is based on the fact that many elements become radioactive when exposed to a neutron flux. The build-up to saturation activity and the decay to zero activity follow an exponential law.

The procedure involves exposing the sample serving as neutron detector to the neutron flux for a measured length of time t and then removing it to a counting position and counting its induced radioactivity beginning at a time t_1 and ending at time t_2, measured from the end of the exposure. The total number of counts during the interval from t_1 to t_2 is first corrected for background. The net number of counts, N, is then reduced to the counting rate which would have been obtained right at the end of exposure, if exposure had been carried to saturation. This particular counting rate will be

* This paper is based on work performed with the Nuclear Shielding Project, Massachusetts Institute of Technology, Cambridge, Mass., which is supported by a joint program of the Office of Naval Research and the Bureau of Ships.

† PRESENT ADDRESS: Gulf Research and Development Company, Pittsburgh 30, Pa.

called $C_{0\,sat}$, the initial saturation counting rate. Then

$$C_{0\,sat} = \frac{N}{\tau(e^{-t_1/\tau} - e^{-t_2/\tau})(1 - e^{-t_i/\tau})} \quad (1)$$

where τ is the mean lifetime of the activity and is equal to $T/0.693$, where T is the half-life, and 0.693 is the natural logarithm of 2.

Detector materials. A frequently used activation detector is indium, which is readily available in pure form, handles easily, and has a convenient resonance for epithermal-neutron distribution measurements as well as a sizable activation cross section for thermal neutrons.

Several activities are induced in In by neutrons. The one under discussion in this paper has a half-life of very nearly 54 min. The most accurate determination appears to be that of Silver (*2*) who reported 53.93 ± 0.13 min. Graves and Walker (*3*) reported 54.0 ± 0.5 min. The mean lifetime τ, corresponding to a half-life of 53.93 min, is 77.8 min.

Other activation detector materials frequently used include: rhodium, which is similar to In in its nuclear properties but quite expensive; silver; gold; iodine; and dysprosium. The first four of these exhibit pronounced resonances in the range of energies just above thermal. Dysprosium is convenient for thermal measurements because of its high activation cross section and the fact that a correction for resonance activation need not be made. The latter may or may not be a handicap depending on whether the resonance-neutron distribution is desired. If it is, In makes an excellent detector, although it is not as sensitive to thermal neutrons as is Dy. For the nuclear properties of the various possible activation-type neutron detector materials, the reader is referred to the compilation of Sullivan (*4*). (It should be noted here, however, that Sullivan has inadvertently interchanged the activation cross sections of the 54-min and 13-sec In activities.) The compilations of cross-section curves by Goldsmith, Ibser, and Feld (*5*) and by Adair (*6*) are also quite useful. Other cross-section compilations which might contain useful information include those of Ross and Story (*7*), Kroeger (*8*), Segrè (*9*) and Way *et al.* (*10*). It is a good idea to check several of these references for a particular cross section. Sometimes wide differences exist in reported values. For example, the thermal-neutron-absorption cross section of silicon is listed by Kroeger as 0.2, by Segrè as 0.25, and by Sullivan as 0.1 barn. The most recent determinations are those of Harris *et al.* (*11*) and of Tittle and Faul (*12*), who obtained 0.16 and 0.15 ± 0.02 barn, respectively. Cross sections of this magnitude are difficult to measure accurately, but they need to be known for purposes such as the one at hand.

Counting the activity. For counting the β-radiation from the activated foil, thin-mica-window beta counters are convenient and fairly stable. When high stability over a period of time is required, it would be well to consider the use of another counting method, or even a detector system different from the activation method. Possibilities include counting the activated foil by use of scintillation counters, and use of boron-lined or boron-trifluoride proportional counters, which can now be obtained commercially with enriched B^{10} but are generally not as compact as foils.

A high-pressure ionization chamber can also be used for determining the activity of the foil, and has the possibility of greater inherent stability than can ordinarily be achieved with G-M counters.

Undesired activities. Other activities than the one being used in the measurement might be induced by the neutrons. For example, an intense activity with a half-life of 13 sec is produced in In by slow neutrons. To

eliminate it, it is only necessary to wait 3 min after exposure before beginning the count, thereby allowing it to decay completely.

An extraneous activity with a half-life longer than the desired one has the effect of increasing the apparent half-life, sometimes to a different degree depending on circumstances. An example is discussed in the next section.

Farmer and Faul (*13*), at the Massachusetts Institute of Technology, found that a low-level background activity apparently produced in In by stray neutrons could be eliminated by storing the foils in a Cd box covered by about 2 in. of paraffin.

Fast Neutron Effects

The activation method is sometimes used to detect fast neutrons by means of a reaction which does not occur appreciably at energies below a certain minimum, known as the threshold. Such threshold detectors are beyond the scope of the present discussion. The interested reader is referred to the recent paper by Cohen (*14*).

A fast activation effect which may give trouble in the case of In is the occurrence of the isomer of In^{115} with a half-life (*4*) of 4.5 hours, which is produced (among other ways) by bombarding In^{115} with fast neutrons. The process is inelastic scattering, in which a neutron enters the nucleus, imparting some of its energy internally, and a neutron leaves with considerably less energy than the one that entered. In a number of instances, the excitation energy of the nucleus is not given up immediately in the form of gamma radiation as is usually the case, but remains for some time before being released. This delayed gamma radiation is a type of radioactivity sometimes called an isomeric transition (I.T.). As for the high-energy activation of In, it is fortunate that high-sensitivity beta counters, such as the thin-mica-window type now available commercially, are relatively insensitive to gamma radiation.

Faul (*15*) has determined quantitatively the effect of the 4.5-hour activity in typical diffusion experiments. Several tests were made in which an In foil was exposed to the fast and slow neutrons present in the neighborhood of a Ra-α-Be neutron source located in an empty pipe surrounded by water. Sufficient exposure was given to saturate both the 4.5-hour and the 54-min activities. At 8 cm from the source, the 4.5-hour activity was about 3% of the 54-min resonance activity, both calculated 90 min after end of exposure. At 16 cm, the corresponding figure was 1%. Just at the end of exposure the ratio in favor of the 54-min activity was even more favorable. In addition, the 4.5-hour activity can be very effectively discriminated against merely by shortening the exposure. Thus, since the activity increases according to the law $A = A_{sat}(1 - e^{-t/\tau})$, where A_{sat} is the saturation activity and t the time measured from the beginning of exposure to the constant neutron flux, a 54-min exposure will take the 54-min activity to half saturation, but the 4.5-hour activity will only be brought to 13% saturation in that time. In experiments in continuous media, the effect will be less because the material between the source and detector reduces the fast neutron flux materially.

If the In-foil activity is counted with a scintillation counter, the 4.5-hour activity (which consists of gamma radiation) will be relatively more important because of the high efficiency of the counter for gamma rays.

Separating Resonance and Thermal Activations

Thermal neutrons can be screened from the detector foil by surrounding it with 0.02 in., or more, of Cd. Cadmium has a large absorption cross sec-

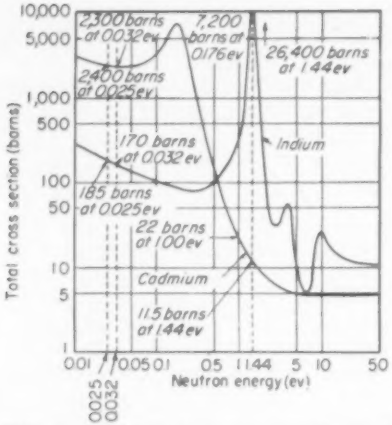

FIG. 1. Total neutron cross sections of Cd and In as functions of neutron energy

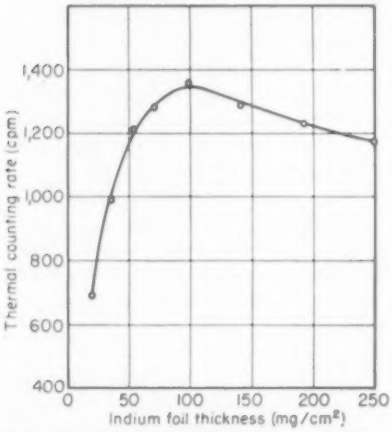

FIG. 2. Variation of thermal counting rate with thickness of foil for In foils 2.5 cm in diameter. Exposure was in water at a fixed distance from a Ra-Be neutron source

tion for thermal neutrons (about 2,300 barns) and also possesses a resonance at 0.176 ev so that the cross section drops off rapidly in the range above 0.3 ev, as shown in Fig. 1. This energy is usually referred to as the approximate value of the Cd cut-off energy, although the term has no exact meaning. Neutrons above the cut-off energy can get through and activate the detector. With In, the activity thus obtained is due almost entirely to the In resonance neutrons, which have an average energy close to 1.4 ev. The resonance peak is 1.44 ev (*5*). If the same foil, or an identical one, is later exposed in the same position, but without the Cd cover, the activation due to all neutrons will be obtained.

In principle, the difference between the readings with and without Cd will be the thermal activation. However, because Cd absorbs some of the resonance neutrons, a correction factor, F_{Cd}, must be applied to the resonance counting rate. This factor is best determined experimentally. A way to get its value for any In thickness and Cd thickness normally employed is discussed in Part II.

Counting Rate vs Foil Thickness

As the detector is made thicker, its sensitivity increases up to a certain point and then begins to decrease slowly because of internal beta-ray absorption and the tendency of a highly absorbing detector to depress the neutron density. Experiments by Anderson at North Texas State College (*16*) show that the In-foil thickness giving the maximum thermal counting rate in water is about 100 mg/cm², as shown in Fig. 2. The thermal counting rate for a 50-mg/cm² foil is about 87%, and for a 150-mg/cm² foil about 96% of the maximum. From the point of view of counting rate, there is little need to use In foils thicker than about 100 mg/cm². Foils of this thickness are quite durable when given reasonable care. An advantage in using foils whose thickness is close to the optimum value is that slight variations in foil thickness in a group of foils will have a minimum effect on their relative sensitivities. The In resonance counting rate does not vary with thickness as rapidly as does the thermal counting

rate. There appears to be a broad maximum around 100–150 mg/cm².

Detector Sensitivity

If the neutron flux is weak, the natural thing to look for is high detector sensitivity. Sometimes, however, a low sensitivity is required because an inconveniently short exposure would be needed to give a counting rate that can be measured on available apparatus. If this is the only difficulty, absorbers can be introduced between foil and counter. It is usually necessary, for comparison purposes, to get a few measurements at intermediate counting rates with and without absorber.

It sometimes happens that the detector must absorb only weakly in order not to introduce an undue error; this is particularly true near the boundaries of a medium. It is convenient to mix the detector material with an inert element to reduce the sensitivity without weakening the detector mechanically. With In, this can be accomplished by alloying the metal with tin in known proportions. Tin is only weakly activated by thermal and epithermal neutrons. An incidental property of the In-Sn alloys is that the ratio of resonance to thermal activity is greater than with pure In.

A thin film of metal can be electroplated onto an inert base, such as nickel. With dysprosium, a paste containing the oxide can be painted in a thin, uniform layer onto an aluminum disk. A similar procedure can be used with iodine, using lead iodide as the active material; or fairly substantial foils can be constructed of a lead iodide-collodion paste dropped onto a mica sheet which can later be stripped off.

A good investment for any neutron laboratory using activation detectors is a set of flat jeweler's bench rolls. A good set will pay for itself in rolling fees saved, not to mention the convenience of having the rolls available. They can also be used for making calibrated absorbers useful for various measurements in nuclear physics.

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". . . the Department of Defense and the Atomic Energy Commission engage the services of about two thirds of the nation's scientists and engineers. If the expanded program contemplated by both agencies materializes, [they may] absorb some three fourths of the nation's technically trained personnel."

—Eric A. Walker, Executive Secretary, Research and Development Board, Cleveland, Ohio, Dec. 30, 1950.

Method for Prevention of Leaching and Fogging in Autoradiographs*

Usefulness of histological autoradiographs can be impaired by washing out (leaching) of radioactive materials, by chemical fogging, and by loss of sensitivity and latent-image stability that occur with wet mounting of specimens. A dry mounting method is proposed to alleviate these difficulties

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IT WAS RECENTLY demonstrated at this laboratory that leaching of plutonium and americium, believed to be firmly bound to tissue proteins, occurred during the histological preparation of the specimens and/or exposure of the autoradiograph. For a true interpretation of the localization of radioactive isotopes in histological sections it is, of course, necessary to eliminate leaching during both tissue preparation and autoradiographic processing.

Leaching during tissue fixation can be kept at a minimum by the use of freezing-dehydration techniques instead of the more conventional methods (*1*). Leaching during exposure may be minimized by the elimination of water or other liquid between the tissue and the emulsion. To replace the previous method of floating a tissue section onto a photographic emulsion with water, a modification of the technique called the "dry mounting method" was devised.

Leaching

To demonstrate leaching during exposure, a mouse was injected with 14 μgm of plutonium in the form of a soluble salt. The spleen was removed, fixed in Zenker's solution, and embedded in paraffin in the usual way. When an autoradiograph of the spleen was made by exposing Nuclear Track NTA emulsion by contact with a dry paraffin-embedded section, a concentration of plutonium alpha tracks was observed at the periphery of the large areas of white pulp. The distribution of silver grains in an autoradiograph obtained by exposing a dry section on dental X-ray film was similar.

This was not the case when a tissue section was floated onto a nuclear-track plate by the usual "wet mounting method." Under these conditions the alpha tracks were observed to be fairly evenly distributed in the emulsion beneath the tissue, and a large number were randomly distributed outside the area of the tissue. With an oil-immersion microscope, one can follow one of these tracks obliquely into the emulsion, and then follow still another track to even greater depth, indicating that radioactive material had migrated vertically as well as laterally.

Similar results were noted when using bone sections although the leaching was not found to be as profuse.

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* This work was done under the auspices of the U. S. Atomic Energy Commission.

† Present address: Lovelace Foundation, Albuquerque, New Mexico.

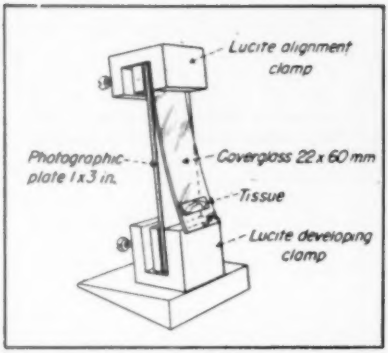


FIG. 1. Alignment and developing clamps in place for developing in dry mounting method. Cellophane envelope is not shown

Photomicrographs showing leaching are given in "Comparison of Methods."

Leaching also occurred when stripping film was used. A tissue section was floated on water onto the cellulose ester side of the stripping film. After long exposures, numerous tracks were found in the emulsion outside the areas covered by the tissue. A similar instance of leaching was demonstrated by Boyd and Williams (Fig. 4 of ref. *2*) when using stripping film to make blood-smear autoradiographs.

Chemical Fogging

When employing the wet mounting method considerable difficulty with chemical fogging was encountered. The various solutions used to deparaffin the tissue, and in some cases the tissue itself, were found to fog the more sensitive beta-sensitive track emulsions. Boyd and Board (*3*) found that an image was produced on a Kodak NTB plate by a normal rat kidney section placed directly in contact with the emulsion. It seemed advisable, therefore, to remove the tissue from the emulsion during development and eliminate all solutions possible from coming in contact with the plate during exposure.

Difficulty in obtaining autoradiographs of histological tissues containing beta-emitting isotopes was also encountered. When paraffin tissue sections containing C^{14} were floated from water onto Ilford G5 or Kodak NTB plates and stored in a plastic light-tight box, few tracks were observed even when the exposure was long enough to obtain an image by dry contact exposure of dental X-ray film. By eliminating water or other solution between the tissue and the emulsion, beta tracks from C^{14} were obtained. The effects of the water film are illustrated in "Comparison of Methods" (Fig. 3).

Boyd and Levi (*4*) report that they obtained good beta autoradiographs of a histological section containing C^{14} by using Kodak NTB2 plates and storing the prepared section in a plastic box in which some calcium chloride crystals had been placed.

Dry Mounting Method

In view of the preceding observations, it seemed necessary to devise a method for handling autoradiographs whereby no water or other solutions should be present between the tissue and emulsion during exposure and only processing solutions should contact the emulsion during development. In addition, the photographic plate should be developed apart from the tissue or smear. The method should provide intimate contact between the specimen and emulsion during exposure, and between specimen and image after development to insure good resolution.

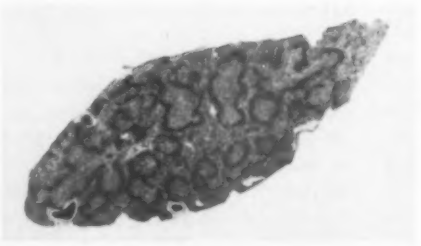
To meet these requirements, a dry mounting method similar in some respects to that of Hoecker and Roofe (*5*) was devised and is being used here.

A set-up like that in Fig. 1 is used. The specimen, either soft tissue, bone section, or blood smear is placed on a 22×60-mm coverglass and held against the emulsion with the alignment clamp. The exposure is then made.

The coverglass and emulsion are

(A) Dry paraffin spleen section on glass slide placed in contact with ultraspeed dental X-ray film during exposure of 48 hours. × 100

(B) Spleen section obtained by floating section onto Kodak NTA emulsion with water. Exposure was 80 hours. × 100



(C) Spleen section obtained by placing dry paraffin section against Kodak NTA emulsion by dry mounting method. Exposure was 71 hours. × 100

FIG. 2. Photomicrographic comparison of leaching of plutonium from soft tissue during exposure after different methods of mounting. A mouse was injected with 74 μgm plutonium; its spleen was removed and fixed in 10% formalin five days later

placed in the developing clamp as shown in Fig. 1 and the emulsion developed according to specifications of the manufacturer. During developing the coverglass is covered with a waterproof cellophane envelope to protect the specimen from the developing solutions.

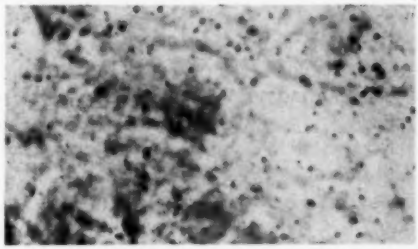
After development and washing, the developing clamp and cellophane envelope are removed and the specimen allowed to return to its original position against the emulsion. When the emulsion has partially dried under the coverglass, the latter can be removed by sliding a razor blade carefully beneath the emulsion and coverglass. Thus the tissue is left in contact with the emulsion and in alignment with its autograph.

Easy transfer of tissue to emulsion is facilitated by omitting the albumen customarily used in securing a section to the coverglass or by superimposing a piece of lens paper between tissue and coverglass. Blood smears are not transferred from the coverglass. Instead, the coverglass with the smear is allowed to dry against the emulsion.

The specimen can be stained on the

(A) Kidney section obtained by mounting dry paraffin section on glass slide and placing it in contact with ultra-speed dental X-ray film during exposure of 1,206 hours. × 100

(B) Section of the cortex of kidney, obtained by floating paraffin section onto Ilford G5 emulsion with water. Exposure was 1,313 hours. × 970



(C) Section of the cortex of kidney, obtained by placing dry paraffin section against Ilford G5 emulsion by the dry mounting method. Exposure was 317 hours. × 970

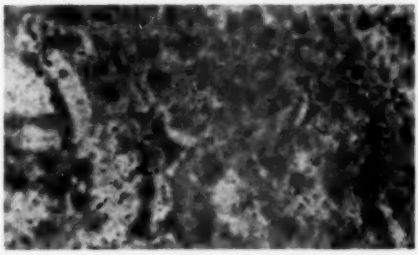


FIG. 3. Photomicrographic comparison of effect of water on sensitivity of track emulsion to beta particles. Rat was injected with nitrogen mustard containing 0.05 μc C^{14}; kidney fixed in 10% formalin

coverglass after development or on emulsion after the transfer. Thus, the radioactive material is not washed from the specimen before exposure.

Comparison of Methods

Results obtained with the dry mounting method are compared with those of other methods in Figs. 2 and 3. Varying degrees of leaching of plutonium from soft tissue is shown in Fig. 2.

The autoradiograph in Fig. 2A was obtained by contact exposure of dental X-ray film. A very sharp outline of the white pulp was made by the exposure of silver grains which showed that no leaching had occurred.

The autoradiograph in Fig. 2B was obtained by floating a paraffin section of the same spleen onto Kodak Nuclear Track NTA emulsion with water and allowing the plate to dry partially before storing in a plastic box. No attempt was made to make sure the emulsion was dry beneath the tissue section. Distribution of tracks around the white pulp was observed, but under a higher magnification than in Fig. 2A. Tracks

were found randomly distributed in the emulsion both beneath and outside the area of the tissue. This cannot be seen in the photomicrograph.

The autoradiograph in Fig. 2C was obtained by the dry mounting method using a serial section on Kodak Nuclear Track NTA emulsion. A sharp exposure pattern appeared as heavy dark lines surrounding the white pulp. This is essentially comparable to that observed in Fig. 2A.

Photomicrographs of autoradiographs of sections of the kidney of a rat injected with nitrogen mustard labeled with C^{14} are shown in Fig. 3. Exposure was made on dental X-ray film by ordinary contact method in Fig. 3A. The activity is seen to be concentrated in the cortex of the kidney.

A section of the cortex of the kidney from the same rat was floated onto Ilford G5 emulsion and allowed to expose. The autoradiograph in Fig. 3B was obtained. Although the exposure time was the same as for Fig. 3A, no tracks were found under the cortical region in Fig. 3B.

A similar cortex section exposed dry on Ilford G5 emulsion resulted in Fig. 3C. Numerous beta tracks can be observed in the cortex although the exposure time was one-quarter that of the other two exposures.

Advantages of Dry Mounting

The advantages of this method are numerous. There is good alignment between tissue and image. Leaching is held at a minimum during the photographic process, and sensitivity and latent image stability of the photographic emulsion are maintained since the emulsion is dry during exposure. No chemical fogging of the emulsion either by chemical solutions or by the tissue itself is apparent; the only solutions coming in contact with the emulsion are the developer and the fixative. The tissue is not injured by these solutions and is under no physical strain because of protection offered by the cellophane envelope. The tissue is also protected by the cellophane envelope from silver deposition during development. Uniform diffusion of the photographic solutions into the emulsion is possible since the photographic plate is separated from the tissue during processing; equal development results.

There is good contact between the specimen and emulsion during exposure and between the specimen and image after development, with resultant good resolution. This is important particularly when using material to be examined under high magnification.

The specimen can be stained before transfer to the emulsion so that the autoradiograph is not obscured. High color contrast in the tissue is possible.

All of the work preparatory to setting up the autoradiograph can be done in the light by an experienced technician. The actual setting up of the autoradiograph takes less time than the wet mounting method. Considerable storage space and deep processing dishes are required, however. Coverglasses often vary in thickness and some experience is required in handling to avoid bending them beyond their limit of flexibility.

* * *

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Radioactive Dust Separation Equipment—III

From the limited data now available, current research is projected to show possible future separation units. The three articles in this series are summarized, and information that must be obtained to establish future design criteria is listed

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MOST EQUIPMENT being developed* to remove radioactive dust from waste gas streams is designed on the basis of established principles.† But engineering aspects of this equipment have not been thoroughly explored for extension to future applications. The experimental investigations have not progressed to the engineering stage.

There is, however, sufficient information available to enable one to estimate the feasibility of applying the newly developed equipment to future installations. Several projected applications are discussed in the following pages. Since filtering techniques have been rather well established, this discussion is limited to applications employing some form of particle growth accompanied by liquid collection techniques.

Included are steam injection, sudden cooling, adiabatic expansion, and sonic vibration. Because of the limited data available, no attempt has been made to present finished design drawings and specifications; the illustrative examples presented here should not be so construed.

Steam Injection

Steam injection could be used in several ways to promote particle growth and thus aid dust separation. It could be used as a prefilter, as a cleanup filter, or could be applied to a plate scrubbing unit.

As a prefilter. The majority of installations handling ventilation air are employing filters of one kind or another. Normal dust loadings are from 1 to 10 grains per 1,000 ft^3, and the carrier is usually at normal atmospheric thermodynamic conditions.

Under these circumstances steam injection could be used in conjunction with a plate scrubber as a prefilter. The function of such a prefilter would be to take the major dust load so that the final cleanup filter would not have to absorb so much of it. This use of steam injection is particularly applicable because the life of a filter is determined by its rate of plugging. One or two plates of a scrubber, used with steam injection, could prolong filter life 10 to 15 times. Another advantage would be that the collected dust could be continuously removed in a liquid stream.

One thing to consider, however, is the thermodynamic condition of the exit carrier from the steam injection stage. Under the same conditions as imposed in the steam injection experiments of

* Equipment being developed was discussed in Part II (NU, May '51, p. 60).

† Basic principles of dust separation and equipment now in use was discussed in Part I (NU, Feb. '51, p. 37).

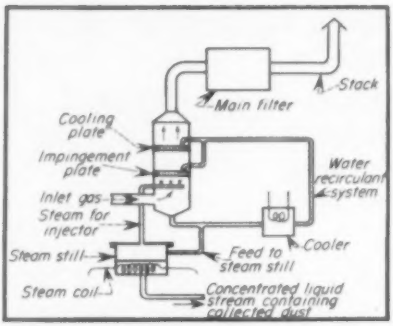

FIG. 14. Steam injection used as a prefilter

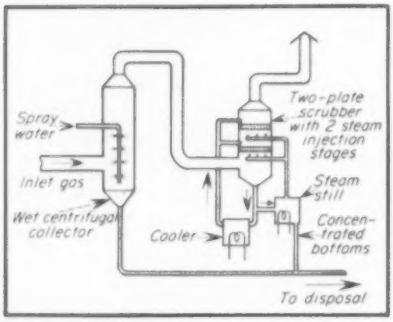

FIG. 15. Steam injection used as a cleanup filter

J. Yellot and of the author (discussed in Part II) the exit carrier would be at about 100° F and saturated. This hot, humid gas might cause serious deterioration of paper-matte filters not built to withstand such humidity. Also, condensation could occur within the filtering medium, especially in deep-bed filters. This could lead to serious plugging of the filter.

One way to avoid condensation is to utilize only one stage of steam injection in a two-stage plate scrubbing tower, as shown in Fig. 14.* The second plate would then cool the gases, thus avoiding condensation in the filter. In addition, the second plate might produce as much as 50% additional cleanup by sudden cooling. This would bring the performance of the entire tower near 90%. Water circulating over the plates is cooled and recirculated; part is drawn off to generate the steam. The collected dust is concentrated in the bottoms, which are drawn off for disposal.

While filter life would be prolonged by using a prefilter in series with a deep-bed filter, there probably would be no appreciable increase in efficiency. As previously noted, a deep-bed filter operates with as little as 50% efficiency after the first 90% of the dust has been removed. Therefore, a deep-bed unit that operates at 99% efficiency alone will probably operate with 50% efficiency behind a prefilter.

The additional pressure drop introduced into the system by the plates (approximately 2 to 3 in. per plate) is less than that usually allowed in the design of the system for buildup of pressure by plugging. Consequently, most installations can take care of the additional pressure drop introduced by the plates.

As a cleanup filter. Steam injection can be used in a final cleanup stage working behind a conventional scrubbing unit. This is particularly applicable where high grain loadings are in evidence; because of preferential wetting, the use of steam injection would not be effective until the major load had been removed. It is most likely that the major portion of dust of very high concentrations would consist of large particles which could be conveniently handled with about 80% efficiency in scrubbers, cyclones, etc., without aid of steam injection. Then steam injection would be applied to the remaining 15%.

Figure 15 shows such an arrangement operating under a pressure drop of about six inches of water. Choice of the primary collector would depend upon the relative concentration and size

* Figs. 1–6 appeared in Part I; Figs. 7–13 in Part II.

range of the dust, but the unit should be designed for continuous removal since it will handle the major load. The steam injection stage provides the final cleanup. If the primary collector employed was a plate scrubbing tower, then the two units could be combined into one by having only the last two or three stages of the scrubber equipped with steam injection.

Applied to a plate scrubbing unit. Figures 16 and 17 show a projected application of a typical plate scrubber employing five stages of steam injection. The tower would not exceed 2 ft in diameter and would be capable of processing 1,000-ft³/min of dust-laden gas carrying 1 grain per 1,000-ft³. From the preliminary experimental data which has been obtained on simulated radioactive dusts (*22, 23*) it should be possible to obtain from 85% to 90% cleanup per stage employing steam injection, and an over-all efficiency of from 99.996% to 99.998%.

Figure 16 shows the details of the plate scrubber. Steam is injected through ring injectors into the gas stream before it enters each of five plates. The dust-laden gases pass through the orifices in the plates and the condensed droplets impinge on the baffle plates located directly above. The gases are then passed through an interstage cooler. While primary cooling occurs on the plate itself, additional cooling is necessary to effect efficient condensation in the succeeding stage. The water for each plate is put into the tower in parallel to derive the maximum cooling effect from the water and to prevent reheating of the gases. Reheating would occur if the water was put through the column in series.

Instead of an interstage cooler, an additional scrubber plate designed specifically for cooling could be inserted. The gas-liquid contact on such a plate will be found to approach 90% of that of a theoretical stage, and this arrangement might prove more economical than a fin-type cooler. Figure 16 shows a typical layout of a two-plate stage in the inset.

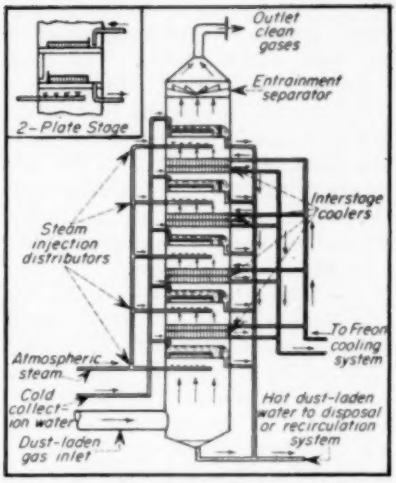

FIG. 16. Five-stage steam injection plate scrubber

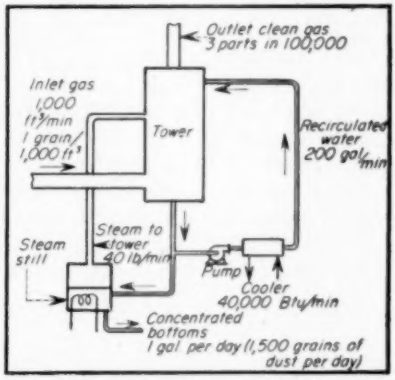
Outlet clean gas 3 parts in 100,000
Inlet gas 1,000 ft³/min 1 grain/ 1,000 ft³
Tower
Recirculated water 200 gal/min
Steam to tower 40 lb/min
Steam still
Pump
Cooler 40,000 Btu/min
Concentrated bottoms 1 gal per day (1,500 grains of dust per day)

FIG. 17. Recirculation system for five-stage steam injection plate scrubber

The pressure drop would run about three to four inches per stage for a two-plate stage. Probably the same over-all pressure drop would obtain for a one-plate stage, the drop through interstage coolers making up the difference.

Figure 17 shows a possible recirculation system to accompany the tower;

this system is designed to provide in a closed system a high concentration of the exit liquid carrier. The main recirculant stream need not build up in concentration beyond the ratio of the grains of dust entering per minute to the steam quantity used, in this case 1 part in 28,000. This minimizes the chance for significant dust generation within the tower by virtue of the liquid recirculant forming a mist.

The bottoms from the steam still can be as concentrated as desired, but it must be assumed that the overhead will carry radioactivity over with it and back into the tower. Depending upon the design of the still, the overhead would be from 10^{-3} to 10^{-6} the concentration of the bottoms. For high concentration of the bottoms it may be necessary to perform the evaporation in a multiple-effect evaporator. In this manner the steam to the last stage would carry back a minimum amount of dust to the tower. It should be remembered that the steam is not processed through all five stages, but only through those stages following its particular point of entrance in the tower. With desired outlet concentrations as low as 1 part in 100,000, the carryback in the steam must be properly accounted for.

For units with as many as five stages, it is not desirable to omit a recirculant system. On the basis of 0.1 pound of steam per pound of air per stage, five stages result in a total consumption of 0.5 pounds per pound of air. The total daily consumption of steam for a 1,000-ft^3/min tower would run about 6,700 gallons per day, which if not recirculated would show up in the outlet dust-laden liquid carrier removed from the tower. This in most instances would be too large an amount of water to handle in a plant requiring the processing of only a 1,000 ft^3/min of air.

To project this idea to the design stage, three basic pieces of information must be further explored:

1. The performance of steam injection has been limited to simulated dusts which were representative of radioactive dust problems; actual tests on radioactive dust have not been made.

2. Nothing is known about the effects of entrainment on efficiencies when the concentrations approach 1 part in 100,000. It may be that entrainment will represent a larger proportion of radioactivity in that form than the dust itself, and thus seriously hamper good efficiencies.

3. The thermodynamics are not well enough established to fix the power requirements. It may be feasible to reduce the amount of steam required in the last stages when most of the dust has been removed. The interstage cooling requirements are not well established either.

The schematic serves only to demonstrate a possible projected application of steam injection. Such a system would be aimed at obtaining high efficiencies, continuous removal of the radioactivity into a very small liquid volume, and small, compact equipment. The most outstanding disadvantage of such a scheme is the power consumption. The main body of the water which is constantly recirculated through the tower must be cooled from approximately 85° F to 60° F, a heat load of over 40,000 Btu per minute. If cooling water is not available at a sufficiently low temperature, this would have to be done by refrigeration, which from a power consumption viewpoint is practically prohibitive. However, further experimentation may prove that the thermodynamic requirements may be sufficiently reduced to cut the power requirements down to more feasible levels of power consumption.

Sudden Cooling

The employment of sudden cooling to effect condensation of water about dust contained in a hot saturated gas has

been described in Part II. The method would find application where the gases to be treated were initially too hot to be treated by steam injection. Any gas above 100° F cannot be treated by steam injection because the condensation will not be significant.

Sudden cooling refers not to the rate at which the gases cool but rather to the fact that a large temperature differential between gases and cooling surfaces is maintained. According to the author's calculations, the ratio of the amount of water which condenses in a fog to the amount which condenses on the surfaces depends upon this temperature differential.

Gases which are above 212° F must be cooled below this temperature before any condensation occurs. They must also be saturated with water vapor. This can be combined by cooling the hot gases with a water spray. After the gases reach 212° F, they should contain as much water vapor as possible, for the first initial condensation will bring down more water than at any other point along the temperature-humidity curve. A ratio of 2 pounds of water vapor per pound of process gas is a practical value.

If the gases to be treated by sudden cooling are initially cold (this would occur if it became more feasible to treat gases by sudden cooling than by steam injection), the gases could be heated and humidified by injection of superheated steam. The steam would have to be superheated to prevent thermal condensation which would provide nuclei in addition to the dust contained therein.

A typical heat balance for one stage of sudden cooling operating on gases initially saturated at 200° F is shown in Fig. 18. Under the conditions shown, which are based entirely on theoretical calculations, approximately one pound of water per pound of air is condensed, of which it is assumed from calculations

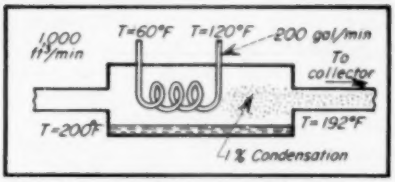

FIG. 18. Estimated heat balance for sudden cooling

that 1% is in the form of the desired fog. This would produce an amount of condensation equivalent to that produced in the experiments on steam injection. Thus 85% cleanup might be approached in this stage when followed by a suitable dust collector.

The heat load of this one stage is almost ten times the heat load produced in a steam injection tower, since only 1% rather than 10% of the steam is converted to moisture. The temperatures involved are considerably higher than those in steam injection, and for this reason the heat can be removed much more economically, completely avoiding the necessity of using refrigeration equipment.

The total temperature drop of only 8° F across the unit makes it easy to maintain a high temperature differential. Utilizing the same rate of water as the steam injection tower, 200 gallons/min, the rise in the cooling water temperature is only 56° F; thus the temperature differential drops from 140° to 72°. The cooling water can be recirculated and passed through a cooling tower, since it does not come into contact with the radioactivity. If sufficient water is available, recirculation is not necessary.

A succeeding cooling stage would have tougher requirements imposed upon it. To condense the same total quantity of water as the first stage, i.e., one pound, the gas temperature would have to be reduced to 100° F. The maintenance of the temperature differential is, therefore, more difficult. A

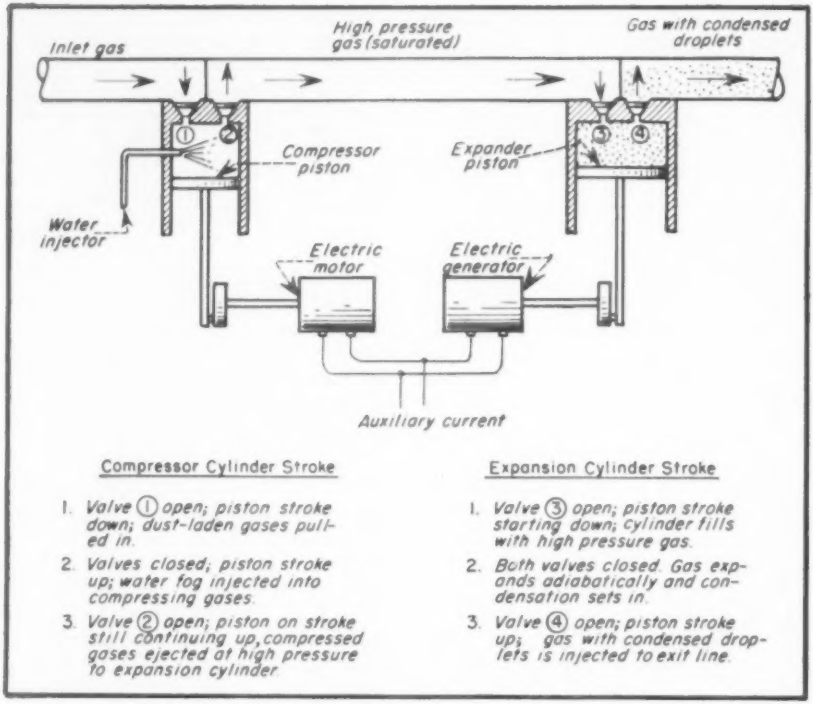
Inlet gas
High pressure gas (saturated)
Gas with condensed droplets
Compressor piston
Expander piston
Water injector
Electric motor
Electric generator
Auxiliary current
Compressor Cylinder Stroke
1. Valve ① open; piston stroke down; dust-laden gases pulled in.
2. Valves closed; piston stroke up; water fog injected into compressing gases.
3. Valve ② open; piston on stroke still continuing up, compressed gases ejected at high pressure to expansion cylinder.
Expansion Cylinder Stroke
1. Valve ③ open; piston stroke starting down; cylinder fills with high pressure gas.
2. Both valves closed. Gas expands adiabatically and condensation sets in.
3. Valve ④ open; piston stroke up; gas with condensed droplets is injected to exit line.

FIG. 19. Use of expansion engine to obtain condensation

third stage would not be effective; below 100° F only about $\frac{1}{100}$ lb of water vapor remains in 1 lb of gas.

A suitable collector must follow each stage. This collector could be centrifugal or impingement plate, depending on the relative size of the droplets produced and the efficiencies required. Wet collection should be maintained for continuous removal.

The plate scrubber again prevails as the answer to combining all the necessary characteristics of collection by sudden cooling. First, the gases may be properly humidified and cooled in the base of the tower by suitable sprays. Next, contact cooling the plates is one of the most efficient methods of achieving sudden cooling of the gases. Third, the condensed droplets are removed as they are formed on the plates. Finally, the plate scrubber can readily be adapted to staging.

Application of sudden cooling by use of a plate tower can be achieved by using commercial equipment without any major change. It may be more advantageous to provide parallel feed to the plates rather than series feed, although the latter may prove satisfactory in these high temperature ranges. The recirculant will have to be cooled by a secondary cooler since it will contain the radioactivity; the type of recirculant system shown for the injection tower could be employed here.

Considerable experimentation is in order, to determine the actual condensation efficiencies which could be realized by each stage, to determine the necessary thermodynamic requirements,

and to determine what dust removal efficiencies can be achieved. The possibility of employing such a piece of equipment in lieu of the injection tower may be an answer to economic considerations. Of special interest would be application for mobile units such as ships, which could use the sea for a coolant.

Adiabatic Expansion

The condensation produced by adiabatic expansion is probably the most efficient from the standpoint of percent of water condensed which falls on the particles. However, from another standpoint, that is, pressure losses, it is the most inefficient method. The pressure losses presently encountered are as high as 25 lb/in^2. This automatically limits the use of adiabatic expansion techniques to handling very small quantities of gases where, despite the pressure loss, the power requirements are low.

Adiabatic expansion practically prohibits the use of stages, since one stage alone produces a large pressure drop. In addition, thermodynamic conditions are destroyed sufficiently to require considerable interposition of cooling coils between stages.

The use of the double-expansion chamber to produce adiabatic expansion has been discussed previously. Little modification of the present experimental apparatus is needed to apply it.

Another method of producing adiabatic expansion would be to employ either a turbine or a reciprocating expansion engine to absorb the work. Such a scheme is shown in Fig. 19. This theoretically could provide for complete recovery of the pressure losses because it is the most efficient thermodynamic mechanism for producing the desired condensation. However, in practical application the frictional losses are quite considerable. Even so, over the range that the double-expansion chamber is employed, the turbine or reciprocating expansion engine might provide a much more economical system.

Sonic Vibration

While equipment being developed shows promise of attaining high efficiencies, continuous removal, and compactness, several outstanding disadvantages accrue which, from an economic standpoint at any rate, prevent this equipment from being a decisive contender in the field of separation. The disadvantages are:

1. The power requirements are very high, this power being chiefly in the form of heat generation and removal and secondarily in the generation of the centrifugal forces necessary for removal of the enlarged particle.

2. The success with which the particle can be enlarged is greatly dependent on the maintenance of proper thermodynamic conditions. This limits the application of such equipment to those process streams which can be maintained in a steady-state condition.

3. The success with which the particle can be enlarged also depends upon the concentration of dust to the extent that there is sufficient water to be condensed on all the particles.

A completely different method of producing an "enlarged" particle and a technique for collection, which shows evidence of being able to circumvent these three objectionable features and still preserve, possibly improve upon, the desirable features of enlargement through condensation, has occurred to the author.

It is known through theory and experiment (Part I) that Brownian motion aids the collection of particles below 0.2 μ through the vibratory motion and migration thus imposed. It is necessary that the collector have interstices in the order of magnitude of the Brownian motion. If a particle in the submicron

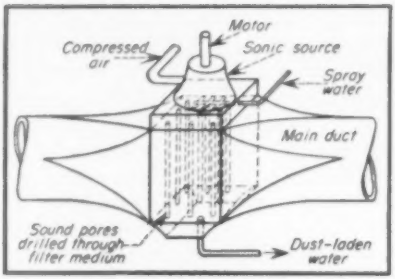

FIG. 20. Sonic filter

range could artifically be given a vibratory motion, two things would result: If the vibrations were in the high frequency range, the particle would be effectively enlarged by virtue of its likelihood of coming into contact with anything encroaching upon the outer dimensions of the path along which it vibrated. The centrifugual force necessary for impingement into or onto a surface is given to the particle by virtue of its velocity in vibrating. Because of the similarity to Brownian motion, this artificial vibration is given the name pseudo-Brownian motion.

Such pseudo-Brownian motion can be produced by sonic vibration. This new application of sonic vibration would provide impingement of the particles upon a stationary impingement surface and would not require dense concentrations of dust. An idea of the construction of a unit using this technique is shown in Fig. 20.

A particle with a pseudo-Brownian motion projected along a vibration path of 1 mm becomes available for collection within interstices of 1 mm if the path of vibration is aligned perpendicular to the free directional path between the impinging surfaces.

Needless to say, a coarse filtering medium would be ineffective for submicron dusts without supplementary aid of pseudo-Brownian motion. But, if the sonic vibration imposed throughout the filtering medium provided sufficient impingement for high collection efficiencies, then other decided advantages accrue.

1. The pressure drop would be negligible, or if preferred, the linear velocity of the gases could be correspondingly greatly increased.

2. It would be possible to provide continuous wet collection by spraying water through the medium without fear of plugging the interstices with the water.

3. The method is completely independent of dust concentration.

4. The method does not call for any thermodynamic requirements or treatments, or for the maintenance of any steady-state conditions except for the sonic vibration and possibly velocity of gases.

The efficiency that could be expected from such a sonic filter is limited by probability of collision and by target efficiency. The former term defines the probability that the particle will have a path that will bring it into collision with the filter medium; the latter term describes the tendency of a particle to slipstream around a target even when the path of the particle is in line for a collision. The probability of collision is made to approach 100% by the vibratory pseudo-Brownian motion imposed. The target efficiency is governed by several factors: size of particle, size and shape of target, and velocity of the particle. Under certain ideal conditions, this target efficiency can be calculated. However, there are many factors that may play an important part in target efficiency and that are not calculable—for instance, electrostatic attraction, Bernoulli forces, vibratory motion producing nonlinearity in slipstream. The final throughput velocity will be governed by the actual target efficiency obtained, and this will only be determined by experiment.

The ability of the sonic vibrations to penetrate the filtering medium without

serious attenuation is one of the major practical problems. Many techniques suggest themselves, but will not be undertaken here. Another serious practical problem is the prevention of regeneration of dust from the action of the vibration on the collector to form a mist.

The complete lack of any power requirements for thermodynamic treatment and for pulling the gases through a high pressure drop leaves the question of power consumption squarely up to the sonic source itself. Sonic sources are presently achieving up to 50% acoustical efficiencies, and in the application of sonic agglomeration are designed to require about 6 kilowatts per 1,000 ft^3 of gas processed. This value is on the upper range of power requirements in equipment presently used, but is far lower than the thermodynamic requirements of steam injection.

In summarizing, the application of sonic vibration to a coarse filtering medium may, in theory, provide high efficiencies; compact equipment; continuous wet collection; independence of performance with respect to variations in thermodynamic conditions, concentration and sizes of particles; and reasonable power consumption commensurate with the performance derived.

Summary

The removal of radioactive dust has rapidly become a major engineering design problem. Its rise from a petty annoyance to a significant factor is due chiefly to the steady increase in volumes of contaminated gases. What was first regarded as a minor irritation must now be handled as a primary engineering concern.

The survey in Part I of presently-used equipment shows that the industry has leaned heavily on commercially available equipment and standard dust handling practices. The units were "plugged in" and it was hoped, not without logical justification, that they would perform on radioactive dusts. A second look indicated that modifications in the systems would have to be introduced to obtain substantial gains in performance. A third look indicated that there were basic shortcomings in the equipment in use, and that there was a need for development of equipment through other approaches to the problem which would obviate the disadvantages now encountered. The survey in Part II of equipment under development shows that such alternate approaches are being considered, but also shows that there are many disadvantages to be conquered.

The most effective equipment now employed is of the low-velocity, fixed-bed, high-efficiency type. The chief disadvantages presently encountered are inability to remove continuously the radioactive dust collected, inability to achieve significant improvements in efficiency, large size and high cost of installations, and unsuitability for compact mobile equipment.

The general approach to circumventing these problems has been to increase the average size of the dust particles through condensation of water about them. Preliminary experimental investigations have given evidence that this technique may enable conventional equipment to achieve high efficiencies and remove the collected dust continuously. The equipment furthermore would be small and compact. The chief disadvantages would probably be the very high power consumption and high initial first costs; also, the condensation technique is limited in use to proper thermodynamic conditions.

Conclusions

The problem has reached a proportion where it should now be removed from the evolutionary approach and viewed in its broadest scope as a basic engineering design problem. From the

(Continued on page 33)

METHODS of FLUORINE and FLUORIDE ANALYSIS—I

In view of increased interest aroused by the atomic-energy program in the technology of fluorine compounds, this annotated bibliography of methods used for their analysis is of current importance. It is the first comprehensive review of the literature, and covers the period from 1816 to 1950

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ANALYTICAL DETERMINATION of fluoride by the lead chlorofluoride, calcium fluoride, aluminum, iron, lanthanum, yttrium, cerium, and thorium methods is considered in Part I of this three-part paper. An extensive record of methods developed or used in Manhattan Project laboratories has been published recently (*1*); therefore only declassified papers that have been separately released are referred to in this compilation. Some reviews of special methods or procedures for certain classes of compounds have appeared earlier: micromethods (*2–5*), in organic compounds (*6–8*), in minerals (*9, 10*), and miscellaneous (*11–23*).

Determination as lead chlorofluoride. The determination of fluoride as lead chlorofluoride was apparently first suggested by Berzelius (*24*).

PbClF is easily filtered (*25*), and would be ideal for gravimetric determination, except for its solubility in water, 3.7×10^{-4} gm/cm³ H_2O at 25° C, which is increased by the presence of acids. Although the precipitate cannot be washed with water, wash solutions of saturated (*26*) or half-saturated $PbCl_2$ (*27, 28*) and saturated PbClF solutions (*29*) have been used. The water solubility of PbClF has prevented adaptation of the method to a microdetermination of fluoride (*30*).

Anions which form insoluble lead salts (phosphate, arsenate, sulfate, and chromate) cannot be present. Sulfate can be removed almost completely by precipitation as $PbSO_4$ at a *p*H more acid than that necessary for the PbClF precipitation; 100 ml of 0.1*N* HNO_3 will dissolve 11 mg $PbSO_4$. However, the dissolved $PbSO_4$ may precipitate later with PbClF to yield high fluoride values.

Small errors occur when the precipitation takes place in the presence of small amounts of borate. Errors due to the solubility of PbClF in acidic solutions can be minimized by maintaining the *p*H at 4.6–4.7 (*28, 31*); but if the solution is more alkaline than *p*H 5.4, $Pb(OH)_2$ will precipitate (*32*).

Starck (*26*) recommended the precipitation of PbClF at the phenolphthalein endpoint; the methyl orange or dimethyl yellow endpoint has been considered more satisfactory because a basic salt is formed at the phenolphthalein endpoint (*27, 33*). To prevent contamination of PbClF with Pb(OH)Cl, a warm lead chloride solution rather than lead acetate was used (*34*); a $PbCl(NO_3)$ solution has also been used as the precipitant (*35*).

* Certain portions of this paper were collected at the SAM Laboratories at Columbia University and at The Institute for Nuclear Studies of the University of Chicago.

While it is essential that the solution contain an excess of chloride, yet so great an excess of chloride as to cause precipitation of $PbCl_2$ must be avoided. If the solution temperature is below 15° C, $PbCl_2$ will crystallize from solution in any event; this error can be obviated by precipitation near 40°. Because precipitation of the last traces of PbClF seems to be slow, the precipitate should age for one hour before filtration (*29*). After precipitation of PbClF, excess chloride has been determined by titration with silver (*36*).

Errors caused by the simultaneous precipitation of other lead salts can be avoided by dissolving the filtered precipitate in 25% nitric acid (*29*). This is followed by a Volhard chloride determination. Lead phosphate carries some chloride out of solution; thus, even the volumetric method may be in error in the presence of phosphate (*31*, *37*). If much chloride is present during aging of the PbClF, lead chlorocarbonate coprecipitates (*38*).

The precipitate, in general, has been dried about 30 min near 150° C. No decomposition of the solid has been observed at 200° C, but it becomes yellow (PbO?) at 400° C (*27*). Precipitation of PbBrF followed by a volumetric determination of the excess bromide in the filtrate has also been suggested (*39*). A collaborative study of the lead chlorofluoride and fluosilicate methods is available (*40*, *41*).

When the fluorides of gallium, indium, and thallium are analyzed by the PbClF method, care must be taken to prevent precipitation of $Ga(OH)_3$, $In(OH)_3$, and Tl_2O_3, contaminated by their respective fluorides (*42*). The precipitation of PbClF has been followed at the dropping mercury electrode and also amperometrically (*43*).

Determination as calcium fluoride. Although the solubility of CaF_2 in water is 1.8×10^{-4} gm/ml at 18° C (*44*), it has been used as a weighing form in the gravimetric determination of fluoride under suitable conditions.

Berzelius originally precipitated CaF_2 from aqueous solution and weighed it as such (*24*, *45*). The method of Lenz (*46*), as described by Deussen (*47*), requires fusion with CaO in platinum; unreacted lime is subsequently extracted from the fusion mass with acetic acid. CaF_2 is presumed to be insoluble in acetic acid although Deussen reported that analyses were always 0.8% low.

Filtration of CaF_2 is sometimes extremely difficult because a colloidal suspension is formed (*48*, *49*). Rose (*50*, *51*) precipitated CaF_2 from a carbonate solution to obtain a mixture of CaF_2 and $CaCO_3$; the carbonate is sufficiently granular to form a porous mat that retains the CaF_2. The mixture is heated and the resultant CaO is leached out with acetic acid. Care must be taken during an ignition of CaF_2 because some CaO is formed on the surface (*45*, *52*, *53*, *54*), particularly when the fluoride is moist. Although the CaF_2-$CaCO_3$ can be leached with acetic acid without previous ignition, as many as four leaches may be required to remove the carbonate completely (*31*).

An indirect determination as CaF_2 involves precipitation from a solution which contains a known amount of oxalate; the CaF_2 and CaC_2O_4 are weighed together and excess oxalate in solution is titrated with permanganate (*55*). Alternatively, CaF_2 has been precipitated by addition of acetic acid which contains calcium acetate, and the excess calcium is determined manganimetrically. Calcium carbonate will coprecipitate when the calcium acetate-acetic acid solution is added, but as the solution becomes more acidic, the $CaCO_3$ will dissolve (*56*).

The simultaneous precipitation has been criticized because of the equilibrium, $CaF_2(s) + C_2O_4^{--} \rightleftarrows CaC_2O_4(s)$

Fluorine is the most powerful oxidizing agent known. It reacts directly with all the elements except nitrogen and the noble gases. Therefore, analysis of gaseous mixtures containing fluorine is difficult because of its reaction with the container and with any confining liquids. It apparently forms compounds only in which it is univalent. Many volatile fluorine compounds are known. Fluorine is almost always determined as a fluoride.

—*G. W. Busch, R. C. Carter, and F. E. McKenna in* "Analytical Chemistry of the Manhattan Project" (*1*)

$+ 2F^-$. Ignition of the mixed CaF_2-CaC_2O_4 precipitate, and determination of the CaO by an HCl titration has been used to overcome this error (*57*). Greater errors are introduced by the use of sodium oxalate than by oxalic acid (*58*). A volumetric determination of the excess calcium in solution after the precipitation was reported to give an accuracy of 0.2–0.4% (*59*). A mixed precipitate of CaF_2-CaC_2O_4 is difficult to filter and wash (*31*); if the fluoride becomes finely divided and forms a suspension, the addition of sufficient KOH to cause an alkaline reaction will cause coagulation of the precipitate (*58*). The presence of large amounts of nitrates was found to coagulate the CaF_2 readily (*30*).

Calcium fluoride is filterable when precipitated in the presence of NH_4OH (*59, 60*), while precipitation from an acetic acid solution has been reported more satisfactory than precipitation from a carbonate solution (*61*). These statements have been challenged because CaF_2 is appreciably soluble in both acetic acid and acetate solutions, and the treatment of CaF_2-$CaCO_3$ mixtures with acetic acid results in the evolution of HF. In addition, CaF_2 precipitated from ammoniacal solutions is contaminated with $CaCO_3$ because of CO_2-absorption from the atmosphere (*62–64*). A CaF_2 precipitate from an ammoniacal solution contains about 5% $CaCO_3$, while the solubility loss is about 4% (*65*).

Precipitation is rapid in the absence of a coprecipitant if a large excess of a precipitating agent, such as $CaCl_2$, is present with paper pulp, such as filter accelerators (*44, 66, 67*). Filtration is also facilitated by addition of a gelatin solution (*68*).

The tendency of CaF_2 to form a colloid has led to a nephelometric determination. Stabilization of the colloid results from the addition of a small amount of a gelatin solution as a protective colloid; there is approximately a 2% decrease in turbidity after six hours. Although the experimental calibration curve does not agree with the assumption that turbidity varies inversely with the fluoride concentration (*69*), the procedure has been reported to be accurate to 1% in the absence of sulfate, phosphate, and arsenate (*70*).

Before precipitation of CaF_2, it is essential that all silica be removed by addition of an ammoniacal solution of zinc (*31, 71*), or by boiling the solution after addition of ammonium carbonate (*56*).

Phosphates, vanadates, chromates, and aluminum and ammonium salts should be removed before precipitation of CaF_2 (*31*). The fluoride content of artificial cryolites has been determined by addition of NaOH and $CaCl_2$ to the solution. This treatment leaves a residue of $NaAlO_2$ and CaF_2 after neutralization to phenolphthalein; excess calcium in the filtrate is determined volumetrically with permanganate (*72*). A 1% accuracy was reported when the precipitation took place in platinum,

while unsatisfactory results were obtained in porcelain (*73*).

Addition of ethanol improves the gravimetric determination as CaF_2 or BaF_2 (*74*). When CaF_2 and $CaSO_4$ are coprecipitated and are washed with a solution saturated with respect to both salts, the fluoride content found is within $\pm 0.1\%$ of the true value (*60, 75*). The combined precipitate can also be converted to $CaSO_4$ by evaporation with an excess of concentrated sulfuric acid (*76*).

Determination by reaction with aluminum. Formation of the ion AlF_6^{---} has been used for the conductometric determination of both aluminum and fluoride (*77*); the minimum obtained in the conductivity curve is sharpened by the addition of ethanol (*78*). $Al(OH)_3$, like the hydroxides of beryllium and the rare earths, but unlike $Fe(OH)_3$, is soluble in neutral solutions of alkali fluorides (*30, 31, 79*).

The fluoaluminate ion is sufficiently more stable than the fluoferrate ion that excess free fluoride can be titrated in the presence of AlF_6^{---} with iron (III), or that aluminum can be determined indirectly by an iron (III) titration through the reaction of an excess of fluoride with aluminum, and the subsequent titration of excess fluoride with iron (III) (*79*). The formation of fluoaluminate can also be used as the basis of an acidimetric analysis. Because the complex ion forms in neutral solution, the hydrolysis due to excess aluminum can be observed by use of phenolphthalein (*80–81*).

Distillation of H_2SiF_6 is hindered by aluminum so that there is only a 70% recovery from 0.5 mg fluoride in the presence of 3 gm $Al_2(SO_4)_3 \cdot 18H_2O$ as compared to the usual 90–95% recoveries (*82*). There are some indications that solid compounds that contain aluminum and fluorine must first be fused with NaOH or a Na_2CO_3-K_2CO_3 mixture to convert the silicon to $NaSiO_2$ before a satisfactory separation of the fluoride can occur (*38, 72, 83*). Aluminum fluoride must be fused with Na_2CO_3 and sand before heating at 90° C with H_2SO_4 to distill H_2SiF_6 (*84*).

If a mineral contains an alumina-to-silica ratio greater than 1:3, the Berzelius method for fluoride analysis is not accurate (*85*).

When morin, a constituent of fustic wood, is added to an aluminum solution, a green fluorescence appears, even when there is as little as 10^{-10} mg Al/ml (*86, 87*). Quenching of the fluorescence by fluorides has been used as an endpoint in the titration of aluminum with fluoride while illuminated with ultraviolet light; the endpoint is not easily recognized, however, in the reverse titration. The fluorescence is extremely sensitive to the experimental conditions (*88*).

The aluminum-aluminon (triammonium aurintricarboxylate) color is also bleached by fluorides, but the results are inconsistent (*89, 90*). Similarly, the aluminum-hematoxylin color is bleached by fluoride and can be used for 2×10^{-5} mg/cm^3 of fluoride (*91, 92*).

Determination by reaction with iron (III). Fluoride reacts with iron (III) in such a way as to suggest the formation of a complex ion whose structure has generally been supposed to be FeF_6^{---}. More recent evidence favors a mixture of the ions, FeF^{++}, FeF_2^{+}, and perhaps some un-ionized FeF_3.

A fluoride solution can be titrated directly with iron (III) chloride. Excess $FeCl_3$ can be observed in an ether extract by its yellow color, which is sharpened by an excess of NaCl in the solution. An accuracy of about 0.2% has been reported for the titration of 250-mg samples (*93*). The method was inaccurate for samples smaller than 100 mg, and it was observed that the optimum amount of excess chloride varies with the sample size (*94*);

samples with 0.5 mg fluoride can be determined at *p*H 4.5 (*95*, *96*).

The endpoint of the fluoride-iron (III) titration can be determined by the appearance of the iron (III) thiocyanate color when excess iron is present (*97*, *98*). The bleaching action of fluoride on the iron (III) thiocyanate complex can be used for the colorimetric determination of 2.5×10^{-4} mg fluoride per ml (*91*, *99–104*).

Sulfate also causes a bleaching action, but a correction can be applied if the sulfate content is known. The amount of sulfate that appears in the distillate after a fluosilicic acid volatilization has been reported as having no effect on the thiocyanate color; this report has been confirmed by the statement that 1–2% sulfate has no effect on the coloration. The optimum $FeCl_3$ concentration appears to be near 0.4*N*. The bleaching action of the fluorides is very sensitive to *p*H, but apparently all buffers for a *p*H less than 7 also affect the solution color (*105*, *106*).

The bleaching action of fluoride on iron (III) acetylacetone is not affected by the acidity of the solution. The bleaching produced does not follow Beer's Law (*105*, *107*). This method is less sensitive to sulfate and chloride than is the thiocyanate method (*107*).

The iron (III)-fluoride complex can be formed in the presence of excess iron, which can then be determined iodometrically (*108*, *109*), or colorimetrically (*101*, *110*). Ferron, 7-iodo-8-hydroxyquinoline-5-sulfonic acid, forms a green solution with iron (III); the color is changed to yellow in the presence of fluoride at *p*H 4.2. An accuracy of about 0.1% is obtained if the sample contains less than 10% fluoride (*111*, *112*).

The iron (II)-iron (III) electrode has been used for the potentiometric titration of fluoride (*113*, *114*); 0.2–60 mg of fluoride per liter can be determined in a 5-ml sample. The relationship between electromotive force and fluoride concentration is empirical and leads to the conclusion that FeF_6^{---} is not formed. There is evidence for a variation from $FeF_{1.81}^{+1.19}$ at 9.5 mg F^- per liter to $FeF_{2.94}^{+0.06}$ at 0.48 mg fluoride per liter with an initial concentration of 5×10^{-4} moles per liter of both iron (III) and iron (II) ions. About a 1% error has been observed in this method of fluoride analysis (*115*).

Salicylic acid forms a violet complex with iron (III) at *p*H 2.7, with an absorption maximum at about 550 mμ. Both fluoride and fluosilicate decrease the complex-formation (*116*). Although the bleaching of the violet complex of iron (III) and 5-sulfosalicylic acid by fluoride at *p*H 3 does not follow Beer's Law, it can be used as a colorimetric method (*117*). The temperature must be controlled, and the color should be measured at 520 mμ (*118*).

Determination as lanthanum fluoride. This compound can be precipitated from fluoride solutions as dilute as $10^{-3}M$. This precipitation is a convenient way to concentrate fluorides (*30*). LaF_3 has been used for the qualitative detection of fluoride (*119–121*); after LaF_3 has been precipitated, it can be treated with concentrated sulfuric acid, and the etching action of the evolved HF can be observed (*122*), or the fluoride can be detected microscopically by the formation of Na_2SiF_6 crystals (*119*, *123*). The ease of qualitative identification of the crystalline fluosilicate can be increased by precipitation in the presence of eosin. At the lower identification limit of 1:50,000, 2 γ of fluoride can be detected by means of the adsorbed dye (*124*).

Lanthanum fluoride can be best precipitated from dilute acetic acid; however, some lanthanum acetate is coprecipitated or perhaps adsorbed on the fluoride. The acetate-fluoride mixture is dried to constant weight at 110° C

The second and third parts of this paper, to be published at a later date, cover the following subjects:

Part II—Determination of fluoride
as thorium fluoride
as zirconium fluoride
as fluosilicic acid

Part III—Determination of fluoride
with titanium
by spectrochemical methods
in fluorocarbons
in gaseous fluorides
Miscellaneous

(the acetate can be ignited to the oxide at red heat without affecting the fluoride). An accuracy of ±0.3% in 70 to 140 mg of fluoride was reported by this procedure (*63*). LaF_3, precipitated from a solution containing 1 gm ammonium acetate and 0.6 ml glacial acetic acid per 100 ml, has a LaF_3:$La(OAc)_3$ ratio of 2:1 (*125*). As little as 5 mg fluoride per ml has been easily precipitated, filtered, and washed. For samples containing 0.03–0.5% fluoride, a corresponding nephelometric method can be used.

Precipitated LaF_3 is peptized by excess lanthanum ion. Addition of a weak acid causes reprecipitation of an impure fluoride, which is not easily filterable. Even pure LaF_3 is not easily filtered and is further affected by the *p*H of the solution when precipitated in the presence of carbonate, oxalate, or tartrate. The mixed precipitate, however, is easily filtered (*124*).

Determination as yttrium fluoride. Yttrium fluoride is the basis of a useful volumetric determination of fluoride in cryolite when there is more than 0.25 mg F^- per ml of solution. The fluoride solution is neutralized to phenolphthalein and is then titrated with $Y(NO_3)_3$ solution, using methyl red as an adsorption indicator. The cerium (III) fluoride method should be used for smaller quantities of fluoride. When sodium, potassium, chloride, or nitrate ions are present in quantities between 0.01 and 0.04 gm/ml, the fluoride analyses by the yttrium method are 1–6% low. The presence of more than 1 mg sulfate per ml results in small positive errors.

In samples containing 54% F^-, a −0.2% deviation was found by the yttrium method as compared to −0.5% by the cerium (III) method and −2% by the PbClF determination (*126*, *127*).

Determination as cerium (III) fluoride. This was thought to be a good compound for a fluoride determination because no stable fluoride complexes of trivalent cerium are known. The titration, however, did not follow the curve expected from theoretical considerations; at some points, deviations were found to be as great as 4% (*79*).

Methyl red is used as the indicator, and a permanent red color is taken as the endpoint. Like LaF_3, cerium (III) fluoride is not easily filtered. Methyl red may indicate the endpoint by selective adsorption. In the presence of excess cerium (III) ion, the precipitated CeF_3 adsorbs the indicator, and in the presence of excess fluoride ion, the CeF_3 adsorbs fluoride (*128*). Another suggestion is that the acid color of methyl red appears at the endpoint because of hydrolysis of excess cerium (III) ion.

In the presence of much solid CeF_3, the endpoint becomes uncertain due to adsorption. High values are obtained in the presence of sulfate ion; low values, in the presence of chloride, while nitrate ions apparently have no effect (*80*). A mixed indicator of methyl red and the monosodium salt of bromocresol green has been used for quantities of fluoride greater than 0.02 mg when titrated with Ce^{+++}. If less than 0.02 mg F^- is present, the same indicator can be used for the thorium titration (*129*).

An indirect titration by the addition

of a known quantity of cerium (III) ion, followed by the oxidation of the excess Ce^{+++} with permanganate in neutral solution, is cumbersome because it is necessary to filter off the MnO_2, CeF_3, and $Ce(OH)_4$ mixture just before the endpoint to prevent adsorption of permanganate by the solids.

Because of adsorption of fluoride on precipitated CeF_3, it is almost impossible to determine the endpoint potentiometrically. In addition, CeF_4 is only slightly soluble, but still more soluble than CeF_3. By use of a ferricyanide-cerium (III)-potassium ferrocyanide electrode, the potentiometric titration is possible. Excess Ce^{+++}, which is added to the fluoride, can be titrated with ferrocyanide. If large amounts of foreign salts are present, no break is observed in the titration curve. An average error of +0.3% was found in samples containing 47% fluoride in the range from 0.1 to 0.5 mg fluoride (*130, 131*).

Determination by formation of thorium fluoride. Precipitation as ThF_4 and ignition to ThO_2 was first suggested (*45*), but the method resulted in an error of 1–10%. The precipitation was carried out in neutral solution. It is not certain that ThF_4 can be precipitated without the simultaneous formation of some Na_2ThF_6. Later it was reported that the compound precipitated was $ThF_4 \cdot 4H_2O$ and that this could be ignited to either ThF_4 or ThO_2 (*132, 133*). A modification of the method involves precipitation of $ThF_4 \cdot 4H_2O$ by excess thorium ion. After filtration of the fluoride precipitate, excess thorium is precipitated as thorium oxalate, which is subsequently oxidized with permanganate (*134*).

The first direct volumetric application of the thorium fluoride precipitation was with sodium alizarinsulfonate (alizarin red) and zirconium nitrate $[Zr(NO_3)_4 \cdot 5H_2O]$ as the indicator, with an average error of −1.7% (*135*). A decrease in the sharpness of the endpoint was reported in the presence of large amounts of ThF_4. Quinalizarin (1,2,5,8-tetrahydroxyanthraquinone) was also suggested as a substitute for the sodium alizarinsulfonate. Because Zr^{+4} forms an insoluble fluoride, it was felt that sodium alizarinsulfonate would be a better indicator than zirconium alizarinsulfonate. Since both the dye and the resultant lake are adsorbed on the precipitated thorium fluoride, the method is best for quantities of fluoride less than 1 mg (*136, 137*).

Zirconium has been omitted from the indicator in the determination of the minute quantities, 0.5–5.0 ppm, of fluoride occurring in natural waters (*138*), after concentration of the solution by evaporation at a *p*H alkaline to litmus or phenolphthalein.

Phosphorites with a low P_2O_5 content and a high aluminum and silica content have been satisfactorily titrated with thorium using zirconium or sodium alizarinsulfonate indicator (*139*) after an H_2SiF_6 distillation. A higher phosphate content requires two distillations: the first from sulfuric acid, the second from perchloric acid (*135, 140*).

A single perchloric acid distillation has been reported to yield an average recovery of 102.4% fluoride. Such positive "perchloric or sulfuric acid errors" have been ascribed to a volatile constituent of the acid (*141*). A collaborative comparison of the pertitanic acid method with the double-distillation method followed by a thorium titration indicated that the titanium method always yields slightly lower analyses than the thorium method. The first distillation was from perchloric acid; the second was from sulfuric acid. The high thorium titration values appear to be due to a decomposition product of the sulfuric acid.

The positive errors have also been ascribed to the presence of chloride and

perchlorate because of their "salt effects" on the alizarin lake. This "salt effect" is not eliminated by the use of a monochloracetate buffer in the titration (*142*, *143*); in fact, one might suppose that such a buffer would introduce a greater "salt error." While sulfate and phosphate are potential sources of "salt errors," they cause a greater error because of the insolubility of thorium phosphate and the slight ionization of thorium sulfate. Addition of Ag_2SO_4 (*14*) or $AgClO_4$ (*144*) to the distillation flask eliminates volatilization of chloride.

Ammonium or potassium produces a smaller "salt effect" than does sodium. It has been suggested that K_2ThF_6 and $(NH_4)_2ThF_6$ may be more soluble than Na_2ThF_6; thus, the difference in "salt effects" may be explained. The possibility of an insoluble ThF_2SO_4 has also been hypothesized (*145*).

The "salt effect" of the neutralized perchloric acid solution has been ascribed to the partial coagulation of the lake (*146*). No error is found if the unneutralized distillate is titrated. If only thorium ions are present, ThF_4 is precipitated; when the distillates are neutralized with sodium hydroxide, $ThF_4 \cdot NaF$ is precipitated (*144*).

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Radioactive Dust Separation Equipment (*Continued from page 25*)

experience and knowledge which is now available in this special field, general basic design criteria should be established. These design considerations should include those of health hazards, economics, logical engineering design, and safe operating practice. The theoretical considerations upon which the design of equipment is based must be thoroughly understood, as well as the practical limitations which are imposed by other more tangible factors.

The establishment of basic design criteria would be aided immeasurably if research and development were directed not only to establish new collection techniques and improve efficiencies of present ones, but also to obtain information along the following channels:

1. Establish performance data of dust removal equipment versus particle size and inlet concentration through controlled test suspension techniques. Prepare curves of performance data and intercorrelate the variables of particle size, concentration, pressure drop stages, and efficiency of removal for various types of equipment. Combine with theoretical calculations to extrapolate for other conditions.

2. Establish series of stack-gas data showing concentration, particle size, thermodynamic conditions, and relative radioactivity. Intercorrelate particle size and concentration. Establish reliable test methods for sampling, analysis, and physical measurements. Intercorrelate with test suspension data. Intercorrelate with theory of behavior of settling and Brownian motion.

3. Evaluate more thoroughly health physics specifications, with the view of easing present specifications through raising of tolerance values, employment of dilution, and evaluation of retention percentage. Set outlet concentrations according to health specifications (presently set as the limit of what can be presently achieved). Compromise if possible on removal down to a certain particle size and dilution of the remainder, remembering that this is subject to agglomeration with larger inert particles. Retention percentage should be investigated. —END

Effect of Weak Betas on the Breakdown of Dielectric Gaps

Experiments indicate that beta-ray irradiation of gaps in electric circuits not only reduces spark-over voltage, but also decreases the range of such voltage. This may allow closer control of voltage in circuit breakers and lightning arresters. The work reported here was done to investigate application to electroventing—using sparks to form holes in materials

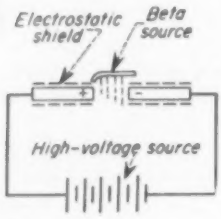
By JEROME J. SURAN*

John W. Meaker & Co., New York, New York

PHENOMENA associated with electric breakdown of dielectric gaps are not completely understood, but it is known that a factor associated with breakdown is the occurrence of ionized particles in the gap at the time the critical breakdown field is applied. Without the presence of such "free" electrons as are released in the ionization of atoms from external radiation sources, breakdown could not be initiated. By increasing the probability of occurrence of ions or electrons in the dielectric gap, the breakdown voltage may be decreased from that required under normal background conditions.

The effect of beta radiation on the breakdown characteristics of several dielectrics was investigated. A 0.65-Mev Sr^{90} and 2.16-Mev Y^{90} mixture on gold foil served as the beta source.†

The electrode geometry used in the study is illustrated below. The radioactive foil was a rectangular strip, 5 mils thick, having an active surface of 1 × ¼ inch. It was curved on the anode side to impart a velocity toward the cathode to the betas in the anode region. The electrodes were brass cylinders 0.38 cm in diameter and were electrostatically shielded in the isotope vicinity except for the gap faces. To prevent an electric field concentration at the sharp edges of the cylinder's perimeters, the electrode gap faces were machined to an approximately convex surface. Prior to the breakdown tests, the electrodes were electrically conditioned‡ to insure against variations arising from surface changes in the metal due to the sparking phenomena.



When solid dielectrics were investigated, the Sr^{90} source was positioned above the cathode in such a way that the active surface of the foil presented a spherical segment to the center of the anode gap face to permit the beta particles to be accelerated through the dielectric and towards the anode.

The breakdown voltage is here defined as that d-c voltage required to initiate and maintain a constant arc across a dielectric gap.

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* Presently connected with Motorola, Inc.

† Manufactured by the United States Radium Corporation and is specified as containing 250 μc of Sr^{90}.

‡ J. G. Trump *et al.* Influence of electrodes on d-c breakdown in gases at high pressure, *Elec. Eng.* **69**, 961 (1950).

Results for Air Gaps

*Gap length** (*inches*)	*Average breakdown voltage†* (d-c)		*Probable error* %	
	EB_b	EB_r	PE_b	PE_r
0.008	1,140	1,070	15.1	4.3
0.016	1,420	1,370	1.7	1.0
0.042	2,050	1,600	5.9	0.8
0.083	3,390	2,520	4.0	1.8
0.125	4,200	3,720	1.8	0.6
0.167	4,980	4,670	2.6	1.1
0.188	5,599	5,060	2.6	1.3

* Measurement is accurate to ± 10 %.
† Measurement is accurate to ± 2 %.

The tabulation above shows the average breakdown voltages for normal background (EB_b) and irradiated conditions (EB_r), together with the associated probable errors (PE_b and PE_r) based on Gaussian probability. The source was placed ½ inch from the center of the gap, and the activity was measured as 2,500 mr/hr at a distance of 1 inch (in air under standard room conditions).

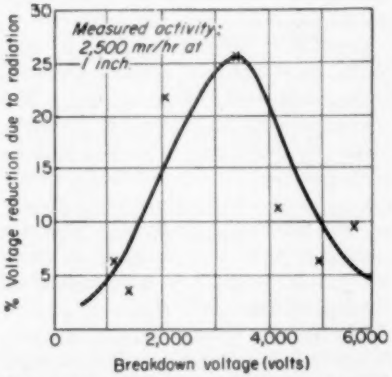
If the reduction in breakdown voltage resulting from exposure of the gap to the Sr^{90} source is expressed as a percentage given by

$$\delta = \frac{EB_b - EB_r}{EB_b} \times 100$$

and is plotted against EB_b, a curve such as that shown at the right is obtained. An optimum gap length exists, which here is approximately 80 mils, corresponding to the normal breakdown voltage of 3,400 volts d-c, where the reduction in breakdown voltage is most pronounced. As gap size is increased above an optimum value, the effective ionization per unit volume of dielectric apparently approaches a constant.

Beta radiation also reduces the breakdown strength of such solid dielectrics as cellophane (du Pont DSB white, 0.0011-inch gage per single ply). With the Sr^{90} source, the reduction in breakdown voltage is as high as 10% for a cellophane gap of one mil. For gaps from 2–5 mils long, the reduction is approximately 3%. Paper dielectrics (Alabama and Swedish krafts) acted similarly.

Polyethylene and polyvinyl-chloride gaps from 2–5 mils were investigated for radiation effects. Although reductions from 1 to 7% of the normal breakdown voltage were evidenced, the probable errors associated with the averages were of the same order of magnitude and hence the results were inconclusive.



Per cent voltage reduction vs normal breakdown voltage for gap irradiated by Sr^{90} foil at radius of ½ inch from gap center

Experimental conclusions. Beta radiation of 2,500 mr/hr intensity (at 1 inch air range) from a Sr^{90}-Y^{90} source will reduce the electric breakdown strength of most common dielectric materials. For air, this reduction will amount to as much as 25%. For dielectric solids, the reduction is as high as 10%, although the results are less consistent than those for air gaps. A radiated air gap will break down at an indicated breakdown voltage with much more certainty than a gap under normal background conditions. For a-c voltages of 60-cycle frequency, the radiation effect upon dielectric breakdown characteristics is approximately the same as that for a d-c potential. —END

BEPO: British Experimental Pile

Construction details for this larger of two Harwell piles have just been released. Graphite moderated and air cooled, Bepo has been in operation more than two years

Bepo (British Experimental Pile) is the larger of the two piles* built at the Atomic Energy Research Establishment, Harwell, England. It has been in operation for more than two years.

Bepo is a graphite-moderated, air-cooled pile with a central thermal-neutron flux of 10^{12} $n/cm^2/sec$. The critical loading is 28 tons of uranium metal; the full uranium load of 40 tons gives rise to an excess reactivity which can be used for experimental purposes or for producing isotopes. The air cooling system was designed to limit the maximum surface temperature of the fuel elements to 200° C.

The general construction of the pile is shown in the diagram. The reacting part is a cube of graphite with 26-ft sides. Through this cube pass 1,849 channels each about $3\frac{1}{2}$ in.^{2} in cross section with $7\frac{1}{4}$ in. between centers. The central 900 of these channels can hold bars of uranium machined into cylindrical rods 12 in. long and 0.9 in. in diameter. The rods are encased in aluminum to prevent oxidation of the uranium and escape of fission products into the cooling air.

Twenty uranium bars are placed in each channel, leaving three feet empty at each end. The channels are loaded starting with the central ones until a right cylinder 20 ft long and 10 ft in radius is formed. The graphite surrounding this central core serves to reflect neutrons which would otherwise escape from the central system.

In addition to the main channels the graphite moderator is perforated with holes for experimental use. The moderator is built up of blocks each $7\frac{1}{4} \times 7\frac{1}{4} \times 29$ in. Grooves are machined in their surfaces so that all the necessary holes are provided after assembly. The 850 tons of graphite in the moderator is made up of 25,000 such blocks.

Blocks of graphite forming thermal columns project from the top and one side of the main moderator.

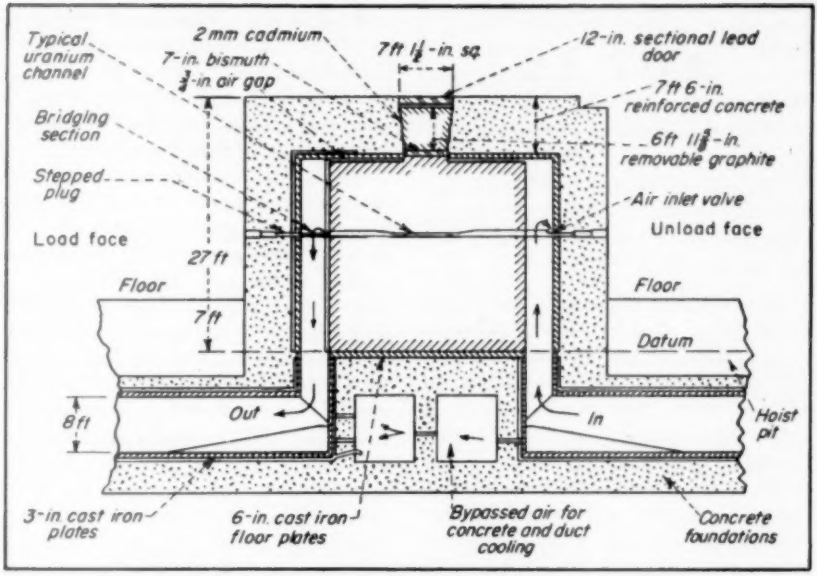
The main outer structure of the pile is a reinforced concrete and steel shell lined with cast iron plates 6 in. thick. A total of about 3,000 tons of concrete and 600 tons of steel were used. The radiation level outside when the pile is running at full power is twice that which exists when the pile is fully shut down.

The cast iron shield provides an initial large attenuation of thermal neutrons and gamma rays so that the bulk of the radiation energy escaping from the reflector is converted into heat. From here the heat can easily be transferred to the cooling air stream circulating past the sides of the cast iron. In this way high temperatures in the concrete are avoided.

About 180,000 ft^3/min of air is required to cool the pile. This air is drawn through the pile, in a single-pass system, by a number of exhausters situated between the pile and the main exhaust stack. A filtering system is used to keep radioactive dust from reaching the 200-ft-high stack.

The cooling system uses an induced air draft rather than a forced draft.

* See the article on GLEEP, the smaller of the two, in Nucleonics **8**, No. 1, 3 (1951)



Longitudinal cross section of the British Experimental Pile

This establishes a negative pressure within the pile with respect to atmosphere. Leakage at the many holes through the shield wall thus involves fresh air inwards and not activated air or dust outwards.

The 900 fuel channels are connected at both the air inlet and outlet ends by 4-ft-wide headers which extend over the whole graphite face. The headers are connected to the 10 × 8-ft underground reinforced concrete ducts of the main air system.

The pile is loaded by pushing in a row of slugs from the load face of the pile. It is unloaded by means of steel rods which push the irradiated uranium slugs out through the unload face into a lead-shielded container. Holes through the shield are plugged to prevent escape of radiation except when an individual channel is being loaded or unloaded. Holes through the shield are stepped so there is no direct path for the escape of radiation.

Control of the pile is effected by four boron-carbide-filled hollow steel rods 2 in. in diameter. These are introduced horizontally into the side of the pile. When fully inserted the rods extend across the reacting core. These rods can be accurately positioned by push-button controls. A second system of 10 similar rods, known as shut-down rods, operate vertically in the pile. They have two positions only, in or out. When both systems are fully inserted the fission rate within the pile is about a milliwatt.

Two methods of measuring the pile power are used. The first is a heat-balance measurement in the cooling air. This, although accurate, has a slow response because of inherent time lags in the system, and is of no use for instantaneous control. The second method, essentially instantaneous, measures the thermal-neutron flux. This method employs ionization chambers within the pile shield which produce a small current proportional to the thermal-neutron flux at that point. —END

BOOKS

A Manual of Artificial Radioisotope Therapy, edited by Paul F. Hahn, Academic Press Inc., New York, 1951, 310 pages, $6.80.

This textbook is limited to the therapeutic field. It is by 16 very able pioneers. Hahn, himself, contributes a brief preface and a short and pointed analysis of the features that make a radioisotope valuable for therapy with mention individually of the two dozen most promising ones. He gives 46 pages to the treatment of "lymphoid-macrophage diseases" by which he means leukemias and lymphoblastomas, with radiocolloids. This chapter has many interesting case reports. Almost nobody else uses Mn^{52} and Au^{198} this way.

Charles Stroebel and Byron Hall take 12 pages for P^{32} in treatment of polycythemia and leukemia, the usual isotope to use.

Hahn's fourth contribution is a 19-page summary of his development of colloidal gold by direct injections for the palliative treatment of cancers, also by intraperitoneal injection for peritoneal implantations. Andrew H. Dowdy gives a 5-page introduction.

Terminology and standards are covered precisely by Robley Evans, with the few really necessary equations and graphs and tables of constants.

Edith Quimby gives dosimetry of internally administered isotopes in 16 pages, as understandably and briefly as is possible for this difficult subject.

The 14-page chapter on isotope procurement is by Paul Aebersold, chief of the AEC Isotopes Division. Health physics, 17 pages, is by Karl Z. Morgan, who is director of the Health Physics Division of Oak Ridge.

Raymond L. Weiland, of Meharry, gives instrumentation 24 careful pages containing what electronic diagrams (5 of them) are necessary to an understanding of the fundamental instruments of the isotope laboratory.

Rulon W. Rawson and Jack B. Trunnell of Memorial Hospital contribute in 35 pages a thorough and understanding essay on cancer of the thyroid treated with I^{131}. This is preceded by 36 pages on diagnosis and treatment of hyperthyroidism by John B. Hursh and John W. Karr of Rochester. C. P. Leblond and J. Gross of McGill have covered the subject of autoradiography beautifully in 23 pages, describing carefully the useful techniques, generously illustrated.

The final chapter is a brief (10-page) description by Edith Quimby and Carl Braestrup of Columbia telling what is necessary in talent and equipment to set up a hospital isotope program. Isotope work is difficult and tedious and little of it is essential in medical practice. These authors say: "This sounds like a formidable amount of preparation for what may turn out to be a comparatively small program." They estimate at the least $2,500 for instruments and somewhat more for space, etc. But it would be easy to spend $50,000 "without being extravagant."

On the whole the book approaches what we have been waiting for. Not only isotope specialists but also radiologists interested in therapy will want this book for practical reference as well as for teaching their pupils.

—R. R. NEWELL, M.D.
Stanford University School of Medicine
San Francisco, California

Cosmic Rays, by Louis Leprince-Ringuet, Prentice-Hall, Inc., New York, 1950, ix + 290 pages, $6.65.

This addition to the scientific literature is a translation from the original

French by Fay Ajzenberg of the University of Wisconsin.

Louis Leprince-Ringuet has made many important contributions to the study of cosmic radiation. The book is an excellent description of the way cosmic-ray research is carried out on the continent of Europe, especially by the French. Excellent pictures are shown of the laboratories that are involved in this work, together with good plates of various observations on cosmic-ray phenomena. The latter half of the book is a good discussion of the present status of our knowledge of the unusual radiation that constantly bombards the atmosphere and our present interpretation of the reactions of this radiation.

The description of Yukawa's theory on page 213 is excellent for one versed in the higher mathematics, including wave mechanics. The tenor of the rest of the book indicates that it is intended for an audience not of this nature. It would seem to the reviewer that a simpler explanation of the development of the theoretical concept of the meson as portrayed in other books would have been somewhat better for this purpose.

On page 235, the statement is made: "Heavy positive mesons decay at rest and form stars." The reviewer knows of no experimental evidence for this statement. The reactions of π^- lead to stars.

There are several more or less trivial errors to which attention should be directed. On page 45, there is the statement "Anderson and Neddermeyer at Pike's Peak," referring to Plates 3.3 and 3.4 which show Valley's equipment on Mt. Evans. On page 93, neither figure 38 nor the accompanying text identifies the letters used in that figure. On page 103, the statement is made that the "magnetic field . . . plays havoc with such essential airplane devices as compasses." Two paragraphs later Anderson's experiments with a powerful magnetic field used in a B-29 are discussed. The two statements are somewhat inconsistent. On page 153 the notations on Plates 10.4 and 10.5 are interchanged.

A somewhat unusual statement, which occurs in the *Note to the American Edition* in the preface of the book, says that "American and English physicists, liberated partially at least from the development of atomic weapons, have returned to their studies." The original French edition of the book is not available to the reviewer and this may be an unfortunate translation. I doubt that many American physicists would admit that they were incarcerated during the war for the development of atomic weapons, nor were they under any compulsion to engage in these developments for any other reason than national loyalty and a sense of duty.

The reader interested in the philosophy of scientific studies will find a great deal of interest in the chapter on "The Personality of Cosmic Radiation." This chapter portrays very well the intense impulsion which drives the students of these natural phenomena.

—URNER LIDDEL
Department of the Navy
Office of Naval Research

BOOKS RECEIVED

Radiochemical Studies: The Fission Products (Div. IV, Vol. 9, of National Nuclear Energy Series; 3 books in the set) edited by Charles D. Coryell and Nathan Sugarman, McGraw-Hill Book Co., Inc., New York, 1951, lxv + 2,086 pages, $18.50 per set.

A New Theory of Gravitation, by Jakob Mandelker, Philosophical Library, New York, 1951, 26 pages, $2.75.

Our Atomic Heritage, by Arnold B. Grobman, University of Florida Press,

(Continued on page 54)

CROSS SECTIONS

Vasodilation and Vasoconstriction Studies with P^{32}*

By R. M. Sodaro† and C. W. Sheppard
Health Physics and Biology Divisions, Oak Ridge National Laboratory
Oak Ridge, Tennessee

Acceptable methods exist for short-term labeling of mammalian erythrocytes with radiophosphorus *in vitro* and their subsequent use in determining blood volume.‡ Relative measurement of radioactivity *in vivo* by the use of externally applied G-M counters is now a familiar principle.

These techniques have been combined to determine changes in the relative amount of blood circulating in the ear of the rabbit produced by the injection of vasodilating and vasoconstricting drugs.

During the experiment the animal is constrained in a conventional rabbit box. Fig. 1 shows the method of applying the G-M tube to the rabbit ear. Any thin, cylindrical, glass counting tube such as the Tracerlab TGC-5 can be employed. The clamp used for securing the ear gives stable mechanical support yet minimum interference with ear circulation. The counting rate was recorded with a General Radio 1500A count-rate meter and Esterline Angus recording milliammeter. A simple laboratory survey instrument might be adapted to such a measurement.

Some preliminary experimentation is required to obtain a convenient counting rate. In our experience a 4.3-kg animal required the injection of 43

* Work done under contract W-7405-Eng-26 for the Atomic Energy Commission.
† National Research Council Fellow in Radiological Physics.
‡ R. T. Nieset *et al.*, *Am. J. Physiol.* **155**, 226 (1948).

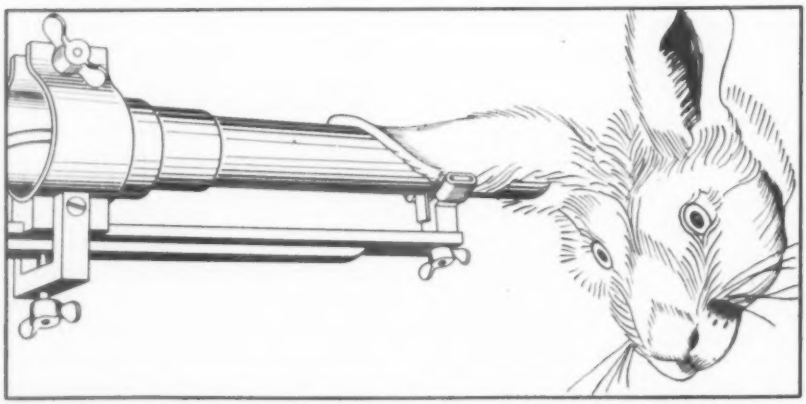


FIG. 1. Experimental arrangement for clipping G-M tube to rabbit's ear

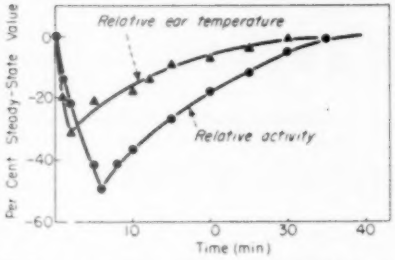


FIG. 2. Vasoconstriction produced by 1 cm³ of adrenalin (1:10,000)

microcuries by marginal vein in the opposite ear. In this way a convenient mid-scale reading on the 20,000-cpm scale was obtained.

The biggest source of variation will be the variable wall thickness of different G-M tubes. It is possible to make successive injections until a satisfactory counting rate is reached.

Figure 2 shows the results, transcribed from the milliammeter chart, after the animal was injected with 1 cm³ of adrenalin (1:10,000). A simultaneous record was obtained of the voltage produced by a 12-junction iron-constantan thermopile attached to the same ear. It is seen that the counting rate closely follows the ear temperature during the vasoconstriction episode.

Figure 3 shows the result of injecting 0.5 mg of histamine acid phosphate. The resultant flushing is more correctly shown by the radioactivity record than by the ear temperature, since the radioactivity should be closely proportional to the volume of blood in the ear. Under normal conditions of vascular tone and room temperature, the temperature of the ear will be close to the physiological value. Thus, increasing the blood in the ear will not materially increase the ear temperature.

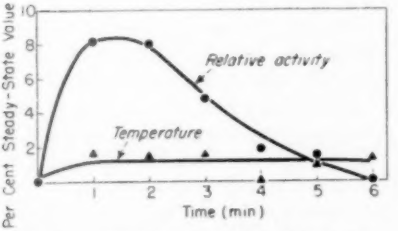


FIG. 3. Vasodilation produced by 0.5 mg histamine acid phosphate

* * *

The authors wish to thank Drs. Jacob Furth and J. B. Kahn of the Oak Ridge National Laboratory for their interest and assistance during the performance of this work.

Household Foil Shields Counter Cables

By Allen McDonald
Metallurgical Laboratories
Sylvania Electric Products, Inc.
Bayside, New York

Spurious counts of external origin frequently interfere with counting of radioactivity. In this laboratory, the electromagnetic field of an induction heater on the floor above caused spurious counts in a proportional counting arrangement.

The counter had been connected to a scaler by a cable shielded with wire mesh. By forming an antenna-like loop in this cable, it was possible to change the background counting rate by holding the loop in various positions. This was how the interference was traced to the induction heater.

Wire-mesh r-f shielding does not attenuate all frequencies equally. It was felt that a solid shield would eliminate the interference.

Ordinary pipe could have been used as the shield, but it would have been bulky and inflexible. We found that the spurious counts were eliminated when the cable was wrapped with household aluminum foil. Scotch tape held the foil in place. —END

NUCLEONIC EVENTS

TWO MORE GROUPS PLAN INDUSTRIAL REACTOR STUDIES

Negotiations are nearing completion for two additional groups to study the feasibility of dual-purpose nuclear reactors for the production of plutonium and power, according to an announcement last month by the Atomic Energy Commission. This brings to four the total number of groups of industrial firms who will participate in the studies.

It had been previously announced that the Monsanto Chemical Company of St. Louis (with its associate, the Union Electric Company of Missouri, of St. Louis) and the Detroit Edison Company of Detroit together with the Dow Chemical Company of Midland, Mich., were interested in the feasibility studies (NU, Feb. '51, p. 86). The additional two proposals were submitted by the Commonwealth Edison Company together with the Public Service Company of Northern Illinois, Chicago, and the Pacific Gas and Electric Company together with the Bechtel Corporation of San Francisco.

The maximum time permitted for each study is twelve months after signing of the AEC's letter of agreement.

Agreements have already been signed with the Dow Chemical-Detroit Edison group and with Commonwealth Edison-Public Service of Northern Illinois group. The Pacific Gas and Electric-Bechtel group has indicated its acceptance of the agreement. Negotations are nearing completion with the Monsanto Chemical Company.

Consideration by the Commission of additional proposals will be postponed for the time being, since it is felt that four study projects is the maximum that can be carried on simultaneously in view of the demands that will be placed on technical personnel of the AEC and its laboratories and contractors. The two laboratories principally concerned are Argonne National Laboratory at Chicago and Oak Ridge National Laboratory at Oak Ridge.

In general, the terms of the agreements already executed provide that the groups will make a survey and study of the Commission's reactor development to (*1*) determine the engineering feasibility of their designing, constructing, and operating a materials- and power-producing reactor; (*2*) examine the economic and technical aspects of building this reactor in the next few years; (*3*) determine the research and development work needed, if any, before such a reactor project can be undertaken; and (*4*) offer recommendation in a report to the Commission concerning such a reactor project and industry's role in undertaking and carrying it out.

All costs will be borne by the companies with the exception of costs to AEC and its contractors incidental to making information and consultation services available. The distribution of the final report submitted on the project will be determined by the Commission.

AEC will grant security clearance after an FBI background investigation for a sufficient number of company personnel to carry out the study. The number of cleared company personnel who will have access to reactor installations will be limited to 15.

OAK RIDGE SUMMER SYMPOSIUM PROGRAM ANNOUNCED

The 1951 Oak Ridge Summer Symposium, which has as its topic "The Role of the Engineer in Nuclear Development" and which will be held in Oak Ridge, Tenn., from August 27 to September 7, has scheduled eight technical sessions. These sessions will occupy the morning hours and are planned to include the following talks:

August 27: Registration and opening addresses; *The Contributions of Engineering to Nuclear Energy Development*, by J. A. Lane, Long-range Reactor Planning Group, ORNL; and *Elementary Nuclear Concepts—I*, by A. M. Weinberg, Research Director, ORNL.

August 28: *Economic Aspects of Atomic Power*, by Sam H. Schurr, Chief Economist, U. S. Bureau of Mines; and *Elementary Nuclear Concepts—II*, by A. M. Weinberg.

August 29: *Elementary Nuclear Concepts—III*, by A. M. Weinberg; *Stable Isotope Separations*, by Manson Benedict, National Research Corporation; and *A Simplified Approach to Reactor Calculations—I*.

August 30: *Elementary Nuclear Concepts—IV*, by A. M. Weinberg; *A Simplified Approach to Reactor Calculations—II; Standards of Radiological Protection and Control*, by K. Z. Morgan, Director, Health Physics Division, ORNL; and *Survey of Reactor Types*, by N. F. Lansing, Reactor Technology Division, ORNL.

September 4: *The Materials of Reactor Construction—I*, by G. E. Evans, Physics Division, ORNL; *A Simplified Approach to Reactor Calculations—III; The Chemical Problems in the Development of Reactors—I*, by J. A. Swartout, Acting Director, Homogeneous Reactor Project, ORNL; and *Environmental Problems of Radioactive Waste Materials*, by R. J. Morton, Health Physics Division, ORNL.

September 5: *A Simplified Approach to Reactor Calculations—IV; Thermal Problems in Reactor Design*, by R. N. Lyon, Reactor Technology Division, ORNL; and *Instrumentation and Control of Reactors*, by J. D. Trimmer, Physics Department, University of Tennessee.

September 6: *The Materials of Reactor Construction—II*, by G. E. Evans; *The Chemical Problems in the Development of Reactors—II*, by J. A. Swartout; *The Treatment of Radioactive Wastes*, by W. K. Eister, Chemical Technology Division, ORNL; and *Hazards Associated with Low-power Research Reactors*, by M. M. Mills, North American Aviation Corporation.

September 7: *Panel Discussion on Nuclear Engineering Education* with R. C. Ernst, Dean, Speed Scientific School, University of Louisville, as chairman. The subjects to be discussed by the participants include: *The Scope of Nuclear Engineering*, by A. M. Weinberg; *The Nuclear Engineering Curriculum at North Carolina State College*, by C. K. Beck, Department of Physics, North Carolina State College; *The Impact of Atomic Energy Developments on the Training of Professional Engineers*, by L. M. K. Boelter, Dean, College of Engineering, University of California; and *The Oak Ridge School of Reactor Technology*, by F. C. Vonderlage, Director, Educational Relations and Training Division, ORNL.

The symposium is open to all interested individuals and is sponsored by the Oak Ridge National Laboratory and the Oak Ridge Institute of Nuclear Studies. Information on housing and other details concerning the symposium can be obtained from William Dryden, Box 117, Oak Ridge, Tenn.

PITZER RESIGNS AS AEC DIRECTOR OF RESEARCH

Kenneth S. Pitzer, effective June 18, is resigning his Atomic Energy Commission post as director of research, to become dean of the College of Chemistry

of the University of California. Dr. Pitzer left his research activities at the University of California late in 1948 to accept a two-year term with the AEC's research division and had extended his stay a half year beyond that.

AEC member Sumner T. Pike, in voicing the regret of the Commission at Dr. Pitzer's leaving, said that the growing effectiveness of the AEC's research program "can be attributed in considerable measure to Dr. Pitzer's critical evaluation of research proposals and scientific performance, combined with his sound business judgment."

Dr. Pitzer's successor has not yet been selected.

WEST FACE OF BROOKHAVEN REACTOR DECLASSIFIED

With the erection of 30-foot-high steel partitions to separate the declassified from the classified area, declassification of the west face of the nuclear reactor at Brookhaven National Laboratory in Upton, New York, has been made official. The declassification action, approved by the Atomic Energy Commission, was taken to permit maximum possible use of the Brookhaven reactor's research capacities.

Designed especially to accommodate a large number of simultaneous experiments in which neutrons are needed, the reactor is the nation's largest research reactor and the only reactor in the northeast. It began operation on August 22, 1950 (NU, Sept. '50, p. 81).

In addition to the facilities of the declassified west face, an unclassified portion of the adjacent reactor laboratory, where special equipment makes possible the study of radioactive samples, has also been made available to researchers.

Scientists wishing to use these facilities will not need AEC security clearance based on an FBI investigation. However, use of the declassified reactor facilities will be subject to approval of the laboratory director of the AEC. Those requesting such use will be required to complete and sign a "Personnel Security Questionnaire," including a listing of all affiliations, which will be reviewed by the Commission's New York Operations Office.

FRANCIS PERRIN NAMED TO HEAD FRENCH AEC

Francis Perrin, professor of atomic and molecular physics at the College of France, has been officially named to the post of High Commissioner of the French Atomic Energy Commission. He had been performing many of the duties of the High Commissioner without title since Frederic Joliet-Curie was removed from the post in January.

NORTH CAROLINA STATE OFFERS SUMMER NUCLEONICS COURSES

North Carolina State College, Raleigh, N. C., will offer, beginning July 23 and as part of its summer program, the second of two six-week courses covering various phases of nucleonics.

These courses are scheduled as part of the school's full undergraduate course of study in Nuclear Engineering leading to the degree of Bachelor of Science in Nuclear Engineering and graduate program leading to the degree of Master of Science in Nuclear Engineering,* but are offered to non-students, as well as regularly enrolled students. Research workers, laboratory technicians, civilian defense personnel, and others desiring short specialized training in nuclear instrumentation, techniques in radioactivity, etc., may register for specific courses offered on the summer program.

Among the courses tentatively scheduled for the session starting on July 23 for six weeks are: Introduction to

* "Undergraduate Curriculum in Nuclear Engineering at North Carolina State College," by C. K. Beck. NUCLEONICS, January, 1951.

Modern Physics, Nuclear Instrumentation, Physical Technology in Radioactivity, Advanced Nuclear Physics, Quantum Mechanics, and Advanced General Physics. Research opportunities in the general field of nuclear technology and engineering are also offered. Registration for this session closes on July 23.

The first such six-week session offering similar courses was started on June 11. Applicants for the courses are accepted to the capacity of existing facilities. Course descriptions, credit-hour information, etc., can be obtained from the college's registration office.

ORNL CYCLOTRON STARTS FULL-TIME OPERATION

An 86-inch cyclotron is now in use at Oak Ridge National Laboratory, the Atomic Energy Commission announced last month. It is the first such accelerator in the Southeast and the first cyclotron to be installed vertically instead of horizontally.

A 250,000-volt radio-frequency system accelerates the protons to an energy of 20 Mev. The machine, which required 500 tons of steel and copper, was designed, fabricated, and assembled in the electromagnetic plant (Y-12) area of Oak Ridge.

NORWEGIAN-DUTCH REACTOR PROJECT COMPLETED

It was disclosed recently in Oslo, Norway, that an international atomic research project, sponsored jointly by Norway and Holland, has just been completed. Established at Kjeller, Norway, the project includes a heavy-water reactor. The reactor, which is scheduled to operate fully by July of this year, is the second to be built in Western Europe outside Britain. The other is in France, where a second one is under construction.

The Kjeller reactor is small in comparison with much larger British models, and its rating of 100 kilowatts is $\frac{1}{40}$ that of the larger of the two Harwell reactors. It will provide Norway and Holland with radioisotopes which heretofore had been supplied to these countries by Harwell.

The seven tons of heavy water for the pile, which was designed and constructed entirely by Norwegians, were provided by Norway, while the three tons of uranium, were provided by Holland.

The project is to be controlled by a commission of three Norwegians and three Dutch representatives. Its charter provides for scientists and industrialists in the two countries and from others to make fullest use of knowledge which is gained.

WEST RELAXES RESTRICTIONS ON GERMAN ATOMIC RESEARCH

Last month the Western Allies redefined restrictions on the use of certain radioactive elements by German scientists to permit a widening of German research into the "peaceful" applications of atomic energy.

The action, taken by the Allied High Commission composed of American, British, and French representatives, gives the Germans permission to separate isotopes, work with uranium, thorium, beryllium and various compounds of these materials, and use Geiger counters and fourteen other types of radiation-measurement devices. The separation of uranium isotopes will be permitted under license but on a limited scale.

It was announced by the Commission that the action was a matter of detailed technical classification rather than a

new policy. In this connection, the Allies continued their ban on the construction of nuclear reactors and tightened restrictions on the use of graphite, rare-earth metals, and mechanical vacuum and vacuum diffusion pumps. Laws still remain "to forbid German industry from participation in any part of the entire field of atomic weapons."

THIRD 3-POWER CONFERENCE ON INSTRUMENTS HELD IN ENGLAND

Harwell, England, played host to the third international cooperative program conference on radiation-detection instruments for two weeks last month. American, British, and Canadian representatives to the conference discussed problems in the design and application of these instruments and visited the facilities of British instrument manufacturers.

Representatives of the United States scheduled to attend were P. R. Bell (Oak Ridge National Laboratory), C. C. Gamertsfelder (General Electric Co.), R. W. Johnston (AEC Radiation Instrument Branch), J. B. H. Kuper (Brookhaven National Laboratory), H. D. Levine (AEC New York Operations Office), F. R. Shonka (Argonne National Laboratory), and R. J. Watts (Los Alamos Scientific Laboratory).

The British delegation included Denis Taylor, E. H. Cooke-Yarborough, J. Sharpe, and K. Kandiak, all of the Atomic Energy Research Establishment at Harwell. George Cowper and I. L. Fowler of the Atomic Energy Research Project at Chalk River represented Canada.

REACTOR SCHOOL TO TRAIN 75 STUDENTS DURING '51–'52

The School of Reactor Technology, established in March, 1951, at the Oak Ridge National Laboratory, will train representatives of 22 United States industrial firms during the 1951–52 term beginning in September, the Atomic Energy Commission recently announced. Both industrial and governmental trainees attend the school and are paid by their employers during the training period (NU, Jan. '50, p. 95; June '50, p. 79; Nov. '50, p. 56).

Of a total of 75 students who will attend the 12-month term, 24 candidates are sponsored by the industrial firms and 8 by Government agencies. The remaining 43 are recent college graduates selected primarily on the basis of their potential contribution to reactor development phases of the national atomic energy program.

During the current 1950–51 term, a total of 43 students attended the school, including representatives of only 4 private companies.

Industrial firms which have sponsored trainees for the 1951–52 term include the following:

Allis-Chalmers Manufacturing Company, Milwaukee Wis.
J. T. Baker Chemical Company, Phillipsburg, N. J.
Boeing Airplane Company, Seattle, Wash.
Brown Instruments Division of Minneapolis Honeywell Regulator Company, Philadelphia, Pa.
Byron Jackson Company, Vernon, Calif.
California Research and Development Company, San Francisco, Calif.
Cities Service Research and Development Company, New York, N. Y.
Consolidated Vultee Aircraft Corporation, Fort Worth, Tex.
Douglas Aircraft Company, Inc., El Segundo, Calif.
Foster Wheeler Corporation, New York, N. Y.
General Mills, Inc., Minneapolis, Minn.
Hercules Powder Company, Wilmington, Del.
Metropolitan Edison Company, Reading, Pa.
National Lead Company, New York, N. Y.
Newport News Shipbuilding & Dry Dock Company, Newport News, Va.
North American Aviation Company, Inc., Downey, Calif.
Pratt & Whitney Aircraft Division of United Aircraft Corporation, East Hartford, Conn.
Public Service Electric & Gas Company, Newark, N. J.
Reynolds Metals Company, Louisville, Ky.
Sinclair Refining Company, Harvey, Ill.
A. O. Smith Corporation, Milwaukee, Wis.
Socony Vacuum Oil Co., Inc., Paulsboro, N. J.

BRITISH PLAN EXTENSIVE ISOTOPES CONFERENCE

A week-long international conference for the exchange of information on the beneficial uses of atomic energy will be held in Oxford, England, from July 16–21.

The largest such conference ever held in Great Britain, it will be devoted to reports by users of radioisotopes on the techniques employed and results obtained.

Some twenty countries will be represented at the conference. All of them, with the exception of the United States, make regular use of radioisotopes from BEPO, the larger of the British reactors at Harwell.

Medical topics will be discussed at the beginning of the week.

For the second half of the week, industrial applications will be discussed, and sessions will also be devoted to agricultural and other research with isotopes.

Visitors will live at various Oxford colleges, and visits may be arranged to Harwell and the Radiochemical Center at Amersham to see some of the non-secret work carried out at these stations.

Inquiries should be addressed to the Secretary (Isotope Conference), A.E.R.E., Harwell, Didcot, Berks., England.

FIRST H. H. GOLDSMITH AWARD TO BE MADE IN FALL

The *Bulletin of the Atomic Scientists* has announced that the first Hyman H. Goldsmith Memorial Award will be made on October 1. The award, in the amount of $200, will be given for an article in the field of science and its relation to public affairs.

Requirements for the article are that it either have been published in America or elsewhere during the year ending July 1, 1951, in any journal or newspaper except the *Bulletin*, or be submitted before July 1, 1951, for exclusive publication in the *Bulletin*.

The *Bulletin* editors are inviting nominations for the award from any interested person.

Dr. Goldsmith, in whose memory the award was created upon his death in 1949, was a founder of the *Bulletin*, head of the Information Division of Brookhaven National Laboratory, and a member of NUCLEONICS' first editorial board (NU, Nov. '49, p. 90).

NATIONAL LEAD TO OPERATE FEED MATERIALS CENTER

The National Lead Company has been selected as contract-operator of the Atomic Energy Commission's Feed Materials Production Center planned for construction near Cincinnati, Ohio. To be located on a 1,200-acre site near the Miami River, the center will include a uranium-ore refinery and other facilities for producing uranium in forms suitable for use at the AEC's fissionable materials production plants.

The new facilities are being designed by the Catalytic Construction Company, and the George A. Fuller Company has been selected as the construction contractor.

IN BRIEF

➤***Plutonium** is now being produced by Great Britain's nuclear reactor at Sellafield, Cumberland. Although no technical information has been released on the Sellafield reactors, it is known that only two of the three piles planned are to be completed. Last year, economy measures forced suspension of work on the third pile.*

➤**Albuquerque, New Mexico,** is the new headquarters for the AEC's Santa Fe Operations office, which since 1947 was located at Los Alamos. The relocation was brought about by the extensive and expanding operation at sites

other than Los Alamos which made it desirable to move the office to a more accessible point. The Santa Fe office is responsible for AEC installations not only in New Mexico but also in Colorado, Texas, Nevada, California, and Eniwetok.

➤***Idaho Operations officials*** *expect the number of permanent employees of the AEC and its contractors working at the Reactor Testing Station and in the Idaho Falls offices to increase from a present total of 600 to about 1,600 by the end of this year. This number does not include construction workers.*

➤**The third training course** in the use of isotopes starts on June 18 at the Atomic Energy Research Establishment in Harwell, England. Twelve students are enrolled for the four-weeks course.

➤***Processing plants*** *to extract uranium from the residue slimes of their South African gold production plants will be erected by both the West Driefontein Gold Mining Company and the Stilfontein Gold Mining Company. The new plants will probably be ready for operation in 1953.*

➤**Operation** of its 450-Mev synchrocyclotron symbolized the formal dedication on May 16 of the University of Chicago's $11-million program for privately supported basic research in its Institute for Nuclear Studies, Institute for the Study of Metals, and Institute of Radiobiology and Biophysics (NU, Feb. '51, p. 60). Completion of the $5-million laboratory buildings and the accelerator, the $2.5-million cost of which was provided by the ONR, comes six years after the organization of the Institutes.

➤***Over 200*** *young European chemists and chemical engineers from Marshall Plan countries will attend the World Chemical Conclave in New York, September 3–13, under the sponsorship of the Economic Cooperation Administration and the Organization for European Economic Cooperation. A similar opportunity for 60 young chemists from other countries—in Asia, Africa, South America, Australia, and New Zealand, as well as in Europe—is provided through a grant by the Ford Foundation.*

NUCLEAR NEWSMAKERS

Nathan H. Woodruff, formerly technical assistant to the manager of the AEC's Oak Ridge Operations, has been appointed acting director of Research and Medicine. He replaces **John H. Roberson** who has accepted a position in Washington, D. C., with the AEC's Division of Research.

Robert F. Bacher, head of the Physics Department at the California Institute of Technology and former AEC commissioner, has been named to chairmanship of the Committee on Atomic Energy of the Research and Development Board of the Department of Defense. The Committee was recently appointed to coordinate the atomic energy aspects of RDB's military research and development program with the AEC.

Charles Crompton, formerly with the AEC Isotopes Division as assistant chief of the radioisotopes branch, has joined the United States Testing Company in Hoboken, N. J. He will direct the work of the company's Applied Radioactivity Division.

Bruno Rossi and **Victor Weisskopf** of the Massachusetts Institute of Technology and **Emilio Segrè** of the University of California are lecturing in Europe under the Fulbright program. Drs. Rossi and Segrè are at the University of Rome, and Dr. Weisskopf is at the University of Bordeaux.

Arthur B. Lamb, editor for 32 years of the *Journal of the American Chemical*

Society, has been chosen to receive the 1951 Austin M. Patterson Award in the Documentation of Chemistry. The award is sponsored by the Dayton Section of the ACS. Dr. Lamb was cited for his services as "a patient and constructive critic, impartial and tactful arbitrator, efficient administrator, inspiring teacher, and able physical chemist."

J. Bion Philipson, formerly program coordinator, has been appointed assistant manager for operations of the AEC's Idaho Operations Office. The Idaho Office also recently announced the appointment of **Thomas W. Dwyer** as safety engineer to replace **Joseph C. Watkins,** who has transferred to the AEC's Kentucky Area Office at Paducah.

W. Müller, German scientist who, with Hans Geiger, developed the Geiger-Müller counter, will visit Australia shortly at the invitation of the Ministry of National Development. Dr. Müller's trip is for the purpose of consulting with Australian industry on technical problems.

William G. Pollard, executive director of the Oak Ridge Institute of Nuclear Studies, has been appointed to a 13-member commission of scientists and educators named by the Board of Control for Southern Regional Education. The commission will have broad responsibility for making recommendations in support of regional arrangements for graduate research and instruction.

Edwin M. McMillan, co-discoverer of neptunium and plutonium, last month received the Research Corporation Scientific Award for 1950. Dr. McMillan, who is professor of physics at the University of California, was given the award, which carries with it a prize of $2,500, for his outstanding researches in nuclear physics.

Geoffrey Wilkinson is leaving Massachusetts Institute of Technology to join the staff of the chemistry department of Harvard University on July 1.

John H. Manley has resigned from the staff of the Los Alamos Scientific Laboratory as research physicist to become head of the physics department of the University of Washington. Associated with the atomic-energy project in various capacities since 1943, Dr. Manley served as technical associate director of Los Alamos, senior responsible reviewer for the AEC, and secretary of the AEC's General Advisory Committee.

MEETINGS

American Society for Testing Metals, 54th Annual Meeting—Chalfonte-Haddon Hall, Atlantic City, N. J., June 18–22

Symposium on Analysis and Metallography of Titanium (June 11–13); Symposium on Surfaces (June 14–16)—Illinois Institute of Technology, Chicago, Ill.

American Physical Society—Vancouver, B. C., June 25–28

American Institute of Electrical Engineers, Summer General Meeting—Royal York Hotel, Toronto, Canada, June 25–29

International Union of Crystallography—Stockholm, Sweden, June 27–July 3

British Institution of Radio Engineers, session on electronic instrumentation in nucleonics—University College, London, England, July 3–4

Congress on Nuclear Physics—Copenhagen, Denmark, July 6–10

International Union of Pure and Applied Physics, General Assembly, Commission on Symbols, Units, and Nomenclature—Copenhagen, Denmark, July 11–14

International Conference on Beneficial Uses of Atomic Energy—Oxford, England, July 16–21

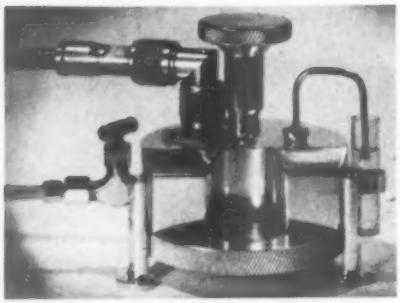
British Association for the Advancement of Science, Annual Meeting—Edinburgh, Scotland, Aug. 8–15

Oak Ridge Summer Symposium (on Nuclear Engineering) sponsored by Oak Ridge National Laboratory and Oak Ridge Institute of Nuclear Studies—Oak Ridge, Tenn., Aug. 27–Sept. 6

Low Temperature Physics Conference, UNESCO Commission for Very Low Temperatures—Oxford, England, Aug. 22–28; Institute International du Froid—London, England, Aug. 29–Sept. 5

American Chemical Society, Diamond Jubilee Meeting—New York, Sept. 3–7

PRODUCTS and MATERIALS



PREFLUSH COUNTER

Radiation Instrument Development Laboratory, 2337 W. 67th St., Chicago 36, Ill. The model 21 is a flow counter for detecting alpha, beta, or gamma rays. For G-M counting the operating voltage is 1,250 volts; the 200-volt plateau is claimed to have a slope of less than 4% over the best 100 volts. For proportional counting the plateau is said to be 300 volts with a slope of less than 1% over the best 100 volts. Sample chambers are rotated by turning a knob; gas flows continuously through counting chamber and preflush position. Background is said to be less than 20 cpm, unshielded.

TWIN TRIODE

General Electric Co., Electronics Park, Syracuse, N. Y. The GL-5844 is a 7-pin, medium-mu tube designed for use in moderately fast digital computers. It directly replaces the 6J6 in most computers and operates at lower heater power. For flip-flop work in binary systems, the tube operates at cut-off and zero bias; cut-off between the triodes balances within a 1 volt limit. Maximum plate voltage is 175 volts and plate dissipation is 0.5 watt; maximum cathode current is 9 ma. For binary service the grid voltage is zero when on and −10 volts when off.

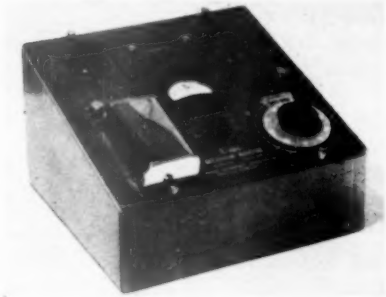
SERVO AMPLIFIER

Industrial Control Co., 1462 Undercliff Ave., New York 52, N. Y. The model 410-B is designed to drive a servomotor with a 5 watt output. The gain is variable with a maximum of 1,000; phase is variable in the range 20 to −140 degrees. Damping is also variable, and these three adjustments are independent of one another. Internal pickup is said to be below 3 mv.

LOW-RANGE POCKET CHAMBER

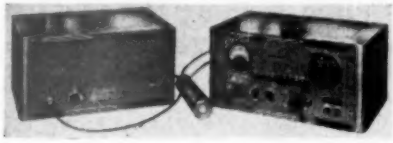
Landsverk Electrometer Co., Pippin Rd., Cincinnati 31, O. For personnel protection, the model L-65 ionization chamber reads the dose of gamma- and X-rays in the range 0–200 mr. The accuracy is said to be ±5%, with back-

ground leakage less than 2% of full scale per day. It is claimed that calibration is independent of energy from 75 kv to 1.5 Mev. Designed to be charged and read on the L-60 battery-operated charger and reader, the chamber clips into the user's pocket.



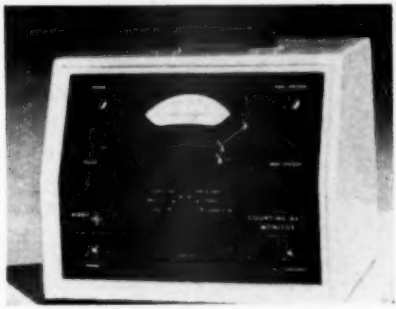
MEGOHM BRIDGE

Special Instruments Laboratory, Inc., 1003 Highland Ave., Knoxville, Tenn. Resistances from 10^7 to 10^{14} ohms may be read directly on the model 144 megohm bridge. It is claimed that the precision over most of the range is 0.1%. Discrepancies in the standard arms of the Wheatstone bridge may be detected and corrections made within the instrument. For this purpose, a set of resistors calibrated by the National Bureau of Standards is supplied with each instrument. The bridge operates from self-contained batteries.



SCINTILLATION NUCLEOMETER

Radiation Counter Laboratories, Inc., 1844 W. 21st St., Chicago 8, Ill. The mark 9, model 5 is composed of a scintillator head, a linear amplifier, and a scaler. The scintillator head contains an anthracene crystal, a 5819 photomultiplier, and a cathode follower, mounted in a iron magnetic shield. The linear amplifier can handle pulses as low as 10 mv with rise times of less than 2 μsec and durations of 3 μsec or longer. The output level is variable from 0 to −10 volts and the pulse has a decay time of less than 3.5 sec. The resolving time of the amplifier is said to be less than 5 μsec. The scale-of-512 scaler has an input sensitivity that can be varied from ½ to 5 volts. Not including the mechanical register, the resolving time of the scaler is 5 μsec.



COUNT-RATE METER

Atomic Instrument Co., 84 Massachusetts Ave., Cambridge 39, Mass. The model 410 is designed for use with either a standard G-M probe or an alpha-scintillation probe. Both audio and visual counting is provided for; four range-selectors make possible readings as high as 200,000 cpm on the meter. Accuracy is said to be 2%. The circuit employs a Schmitt discriminator. High voltage is variable up to 2,000 volts.

LIQUID-LEVEL GAGE

Isotopes Products, Ltd., 8th Line North, Oakville, Ontario, Canada (P. O. Box 127). This portable gage detects the level of liquids in containers by reflec-

tion. It makes use of a 20-millicurie source of Cs^{134} embedded in a 6-in. lead block with a ¼-in. collimated aperture. The detector, shielded by lead from the source, is a sodium iodide crystal and a 931A photomultiplier. Power is supplied by two vibrators fed from 6-volt batteries. Readings are made through the tank wall. The instrument is said to operate well on walls up to ½ in. thick, and results better than ±⅛ in. may be obtained.

GAUSSMETER

Dyna Labs, Inc., 132 Lafayette St., New York 13, N. Y. The probe of the model D-79 gaussmeter is nonmagnetic so that the field is not disturbed. A steady reading is given as long as the probe is held in the field; no pulling or other movement is necessary. Magnitude and direction of flux density can be read for an air gap as small as 0.025 in. thick and 0.01 $in.^2$ in area. Six scale selections cover the range 10–30,000 gauss with an accuracy of 2½% for both a-c and d-c fields.

PHOTON COUNTERS

Nuclear Research Corp., 2707 Federal St., Philadelphia 46, Pa. Four G-M counters for detecting the photons from scintillation crystals are available. The model NRG-50 has a mesh cathode giving transmission at about 2,500 A.U. The model NRG-51 has a bubble window giving transmission at about 2,000 A.U. The model NRG-52 is a zinc-cathode counter. It is said to give good response in the interval 2,000–4,300 A.U.; peak transmission is in the vicinity of 3,300 A.U. The model NRG-53 has either a brass or copper cathode and gives transmission at wavelengths as high as 7,000 A.U. For general use, these counters must be housed in light-tight cavities.

LITERATURE AVAILABLE

Gas-Flow Control. Bulletin 11-D describes laboratory gas-flow control apparatus. *Kahl Scientific Instrument Corp., Box 1166, El Cajon, Cal.*

Transformers. Illustrated brochure GEA-4626 shows line of current and voltage instrument transformers. *General Electric Co., Syracuse 5, N. Y.*

Speed Reducers. Bulletins A-470 and A-602 give data on double and single reduction torque-arm reducers. *Dodge Mfg. Co., Mishawaka, Ind.*

Mills and Cutters. Illustrated catalog lists milling and cutting heads. *Severance Tool Industries, Inc., Saginaw, Mich.*

Components. Catalogs list line of electronic components and sheet-metal products. *Bud Radio, Inc., 2118 E. 55th St., Dept. I-6, Cleveland, O.*

Potentiometers. Technical data chart gives data on line of potentiometers. *Helipot Corp., 912 Meridian St., So. Pasadena, Cal.*

Instruments. Data on spectrum analyzers, amplifiers, and power units is given in an illustrated catalog. *Polarad Electronics Corp., 100 Metropolitan Ave., Brooklyn 11, N. Y.*

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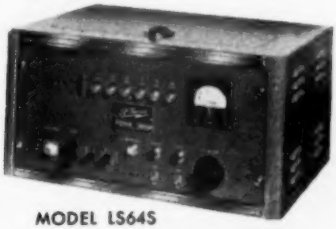
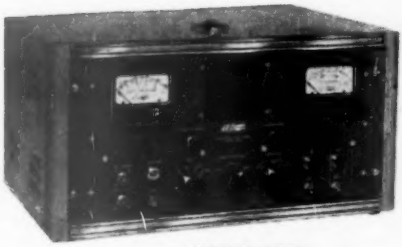
Compact modern unit, designed to speed up laboratory counting. Total count quickly indicated by direct reading scale. No extra computing. Total count on 100 scale up to 999,999. Featuring hermetically sealed components. Compact—11" wide, 9½" high, 18" deep. Geiger Tube Extra.



MODEL LS64S



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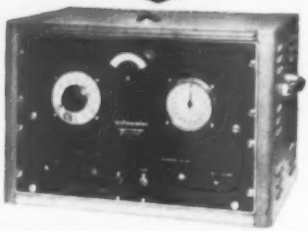

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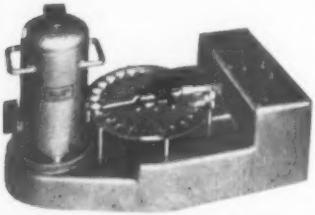

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Books (*Continued from page 39*)

Gainesville, Fla., 1951, xii + 147 pages, $2.95. A description for laymen of the hereditary effects of radiation.

Advances in Electronics, Vol. III, edited by L. Marton, Academic Press Inc., New York, 1951, xii + 357 pages, $7.50. Contains among its nine chapters on recent developments in electronic research one on velocity modulated tubes and two on magnetron theory.

OTHER LITERATURE

An International Bibliography on Atomic Energy, Vol. II, Scientific Aspects (1951). This outstanding 880-page work by the United Nations Atomic Energy Group, Department of Security Council Affairs, contains 24,282 entries of technical books and articles on the scientific aspects of atomic energy published in all parts of the world from 1925-1949. Brief introductory essays by leading scientists serve to preface the five major sections of the bibliography which are as follows: Fundamental Nuclear Science; The Physics and Engineering of Nuclear Reactors; The Biological and Medical Effects of High-energy Radiations; Isotopes in Biology and Medicine; and Applications of Radioactive Tracers in Non-biological Sciences and Technology. *Available from Columbia University Press, 2960 Broadway, New York 27, N. Y., at $10, and from authorized sales agents for United Nations publications in other countries and national currencies.*

Supplement 1 to "Nuclear Data," National Bureau of Standards Circular 499. Issued April 25, 1951, this is the January to July, 1950, supplement to the collection of experimental values of half-lives, radiation energies, relative isotopic abundances, nuclear moments, and cross sections, compiled by the

NBS Nuclear Data Group (Katharine Way, Marion Wood, Karin Thew). *NBS Circular 499 is available from the Superintendent of Documents, U. S. Govt. Printing Office, Washington 25, D. C., $4.25; this price also includes three supplements (see above) that include data reported during the three six-month periods ending July 1, 1950, January 1, 1951, and July 1, 1951. The supplements will be mailed automatically to purchasers of the table as soon as each becomes available.*

The Development and Future of Nuclear Energy, by Sir John Cockcroft (1950, 23 pages). The Romanes Lecture delivered in the Sheldonian Theatre, June, 1950. *Available from Oxford University Press, New York, $0.60.*

Correction Tables for Radioactive Decay, by Barbara S. Smith (National Institutes of Health report, April, 1951, Public Health Service, Federal Security Agency). In this 22-page report, tables of decay correction factors to four-place accuracy are presented for various biologically important radioisotopes, based on half-life estimates in current acceptance. *Copies of these tables are obtainable by letter of request to the National Institutes of Health, Scientific Reports Branch, Bethesda 14, Md.*

Atomic Energy Commission Document Price List No. 18 (issued March, 1951). A listing of all AEC publications made available for sale since October, 1950. *Copy of price list available without cost from Office of Technical Services, Dept. of Commerce, Washington 25, D. C.*

A New Method of Radioactive Standard Calibration, by Howard H. Seliger (RP2163). A 7-page reprint in which a method is described for making G-M counter measurements of different activity samples independent of intermittent disturbing effects. An example

(Continued on next page)

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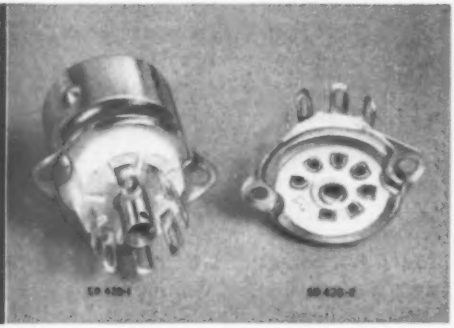

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Books *(Continued from page 55)*

of a calibration procedure is given in which it has been possible to achieve a higher degree of accuracy in only 30% of original counting time. *Available from Superintendent of Documents, U. S. Govt. Printing Office, Washington 25, D. C., $0.10.*

The Civil Defense Alert (Vol. 1, No. 1, April, 1951, 8 pages). First issue of a monthly FCDA-published newsletter for state and local civil defense staffs. *Available from Superintendent of Documents, U. S. Govt. Printing Office, Washington 25, D. C., $0.60/year.*

Metrical Geometry Contact Transformations and Nuclear Physics, by J. Mariani. A 28-page, formal treatise on the subject. *Available without cost from the Institute of Applied Biology, 101 Lafayette Avenue, Brooklyn 17, N. Y.*

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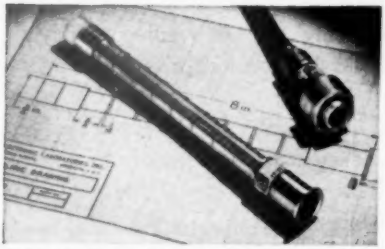

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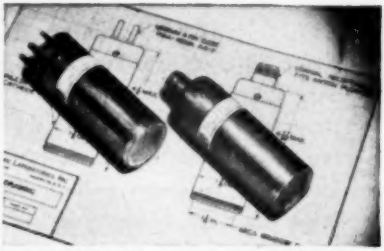

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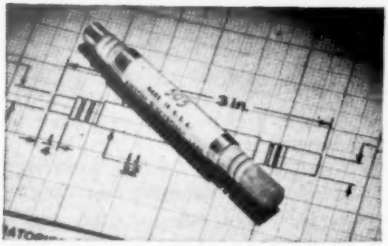

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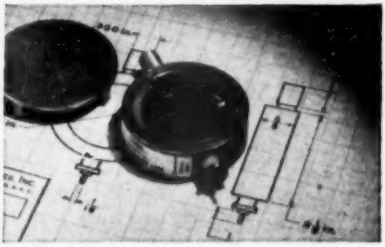

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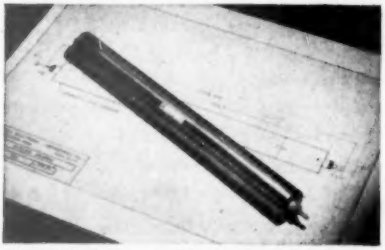

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held. Primary emphasis will be on the techniques and uses of radioisotopes.

NUCLEONICS believes that the time is ripe for an annual meeting in this country which would be broader in scope than the British conference. The first meeting might be a two-to-four-day affair with the majority of the papers based on original work (developmental rather than fundamental, however). Interspersed among these papers would be three or four broader talks on technical problems of current interest. There might be an evening round-table discussion on a general-interest technical problem, perhaps one of a controversial nature.

It must be emphasized that the most important criterion for selection of papers and talks is that the subject matter must be of interest to scientists or engineers of more than one discipline. This would encourage the cross-fertilization of ideas so necessary in the nucleonics field.

Sponsorship of the meeting could be undertaken by any one of the major societies, or perhaps by an organization such as the Oak Ridge Institute of Nuclear Studies, or perhaps by a governmental agency such as AEC or ONR.

If any group effort to arrange such a meeting is initiated, we will gladly offer what help we can give, especially in publicizing the meeting. —*J.D.L.*

viewers (authorities on the subject of the manuscript) check about 25% of the papers we receive. This, of course, varies from month to month and in some periods will rise as high as 50%.

It is of interest to point out that our system of considering manuscripts is quite similar to that used by other journals. For example, the Physical Review *does not have more than 50% of the papers it receives reviewed by outside referees. Some journals, particularly foreign ones, use the philosophy of allowing the author to take the responsibility for the quality of his manuscript, rather than the journal.*

• **It is distinctly** a pleasure to an editor when he comes across a well-written manuscript. We partook of such a delight recently when, after spending an evening at home in a sleep-inducing armchair, we advanced through a stack of articles and reached one entitled, "The Effects of Solution Composition in a G-M Counter for Liquid Samples," by G. Rose and W. W. Emery of London, England. We had come to the point where our eyes were beginning to close and were startled to find that, once we started to read this paper, we couldn't stop until we finished it. We suggest you look for it in our July issue.

• ***Here are two*** *unrelated but interesting facts recently mentioned by an AEC official: (1) there are now 10–12,000 scientists working in the atomic energy program, and (2) of the reports issued by the AEC based on work done for it, one third appear in the open literature, one third appear in the National Nuclear Energy Series, and one third do not get published.*

—*J.D.L.*

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RCA WV-84A Ultra-Sensitive DC Microammeter reads from 0.001 microampere to 1000 microamperes in six ranges. Also useful for measuring high values of resistance, or as a high-resistance voltmeter with a sensitivity of 100 megohms per volt. Accuracy, ±5% or better . . . indispensable for conducting experiments involving minute values of current.

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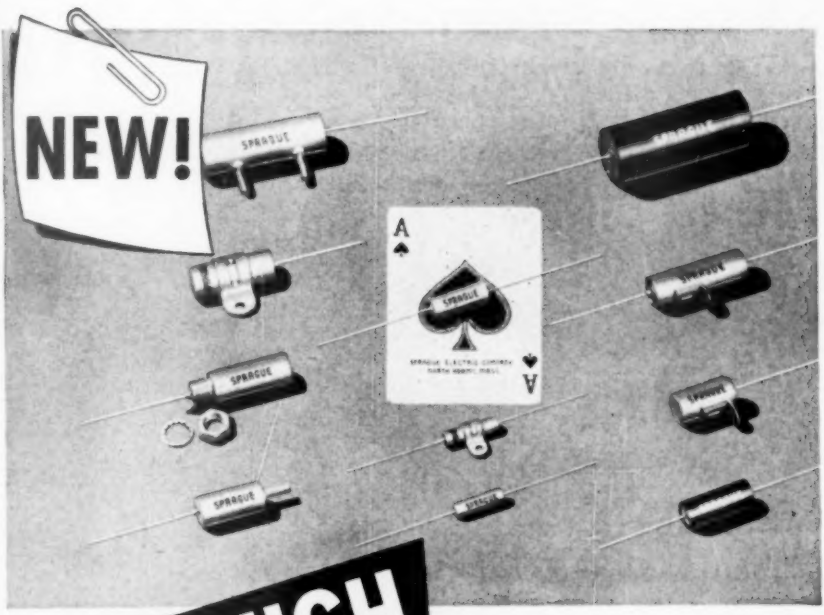

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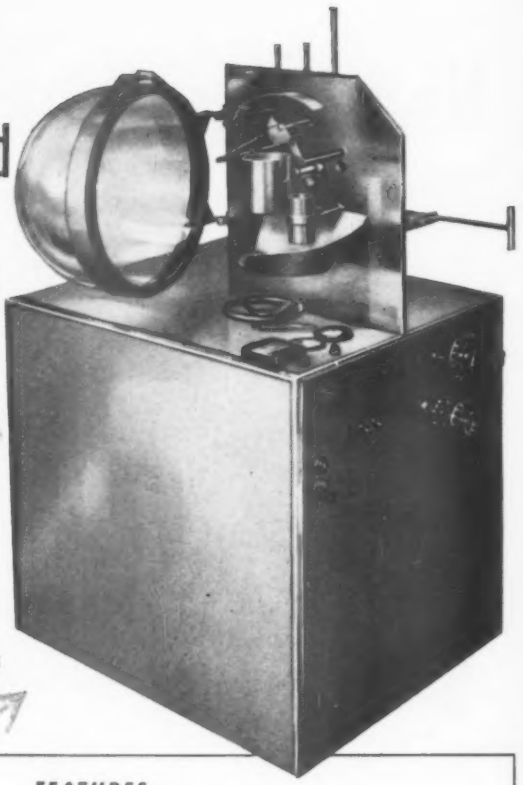

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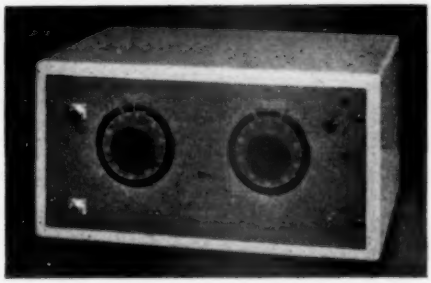

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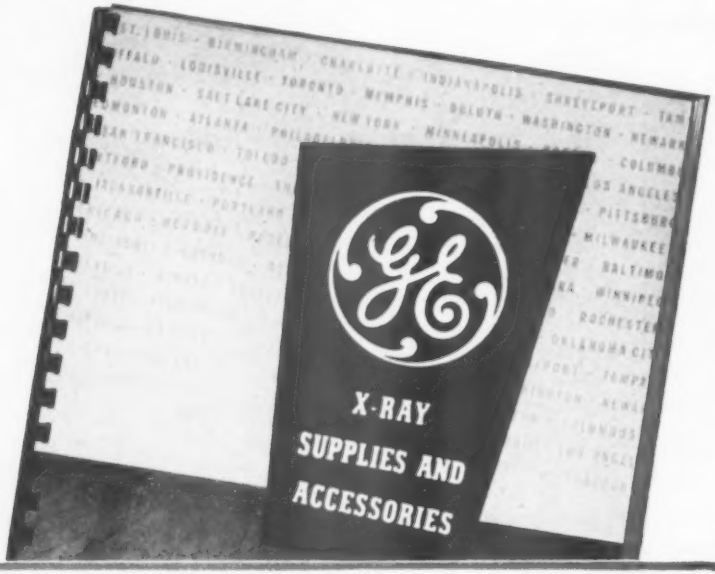

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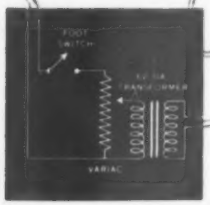
marion methods

electrify

TWEEZER SOLDERING

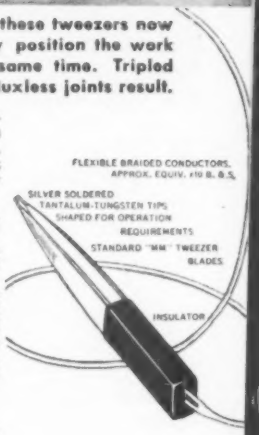


Electrified by Marion, these tweezers now do double duty. They position the work and solder it at the same time. Tripled production and finer fluxless joints result.

Help yourself to **marion methods**

Marion uses this *Method* of Tweezer Soldering for many fine soldering operations. Resistance heating *in the work* itself and conducted heat from the tips combine to give greatly increased soldering rates on pretinned components. Because the tweezers develop little heat themselves, adjacent component damage is avoided. These tweezers permit an *inexperienced* worker to rapidly acquire a high degree of skill.

NOT FOR SALE — You can make electric soldering tweezers of your own. Those shown here have standard "MM" blades, separated and insulated by bakelite. They are assembled and wired as illustrated. By varying the voltage, the tip cross section, and the contact area, you can adapt this tool to your specific application.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STANDARD "MM" TWEEZER BLADES
INSULATOR

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marion meters

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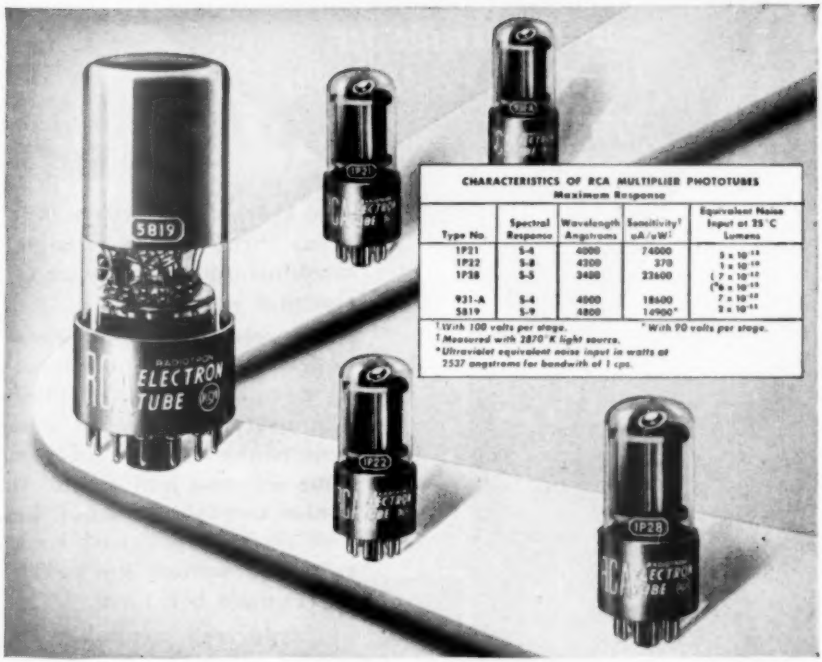

CHARACTERISTICS OF RCA MULTIPLIER PHOTOTUBES
Maximum Response

Type No.	Spectral Response	Wavelength Angstroms	Sensitivity† uA/uW†	Equivalent Noise Input at 25°C Lumens
1P21	S-4	4000	74000	5×10^{-13}
1P22	S-8	4200	370	1×10^{-10}
1P28	S-5	3400	23600	1.7×10^{-12} (*6×10^{-13})
931-A	S-4	4000	18600	7×10^{-13}
5819	S-9	4800	14900*	2×10^{-11}

† With 100 volts per stage. * With 90 volts per stage.
† Measured with 2870°K light source.
* Ultraviolet equivalent noise input in watts at 2537 angstroms for bandwith of 1 cps.

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• • •

For further information write RCA, Commercial Engineering, Section 62FR, Harrison, N. J.

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mark-time
"5400" bell
time switch

first
where quality
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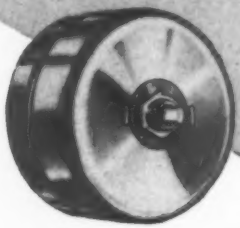

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U.L. approved for 20 ampere, 125 volt or 10 ampere, 250 volt operation. A.C. only. Timings from 60 seconds to 5 hours.
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2. TESTING AND SERVICING
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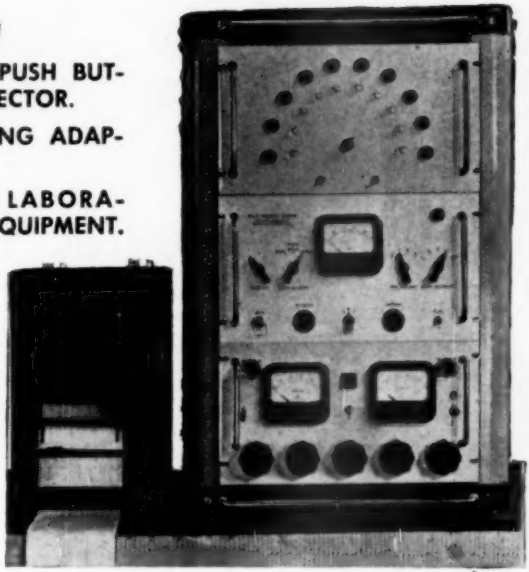

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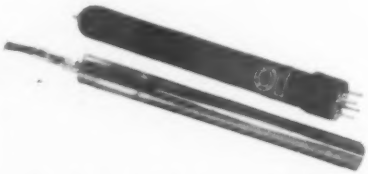

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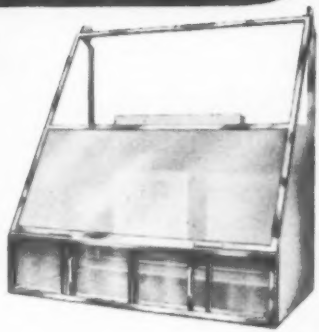

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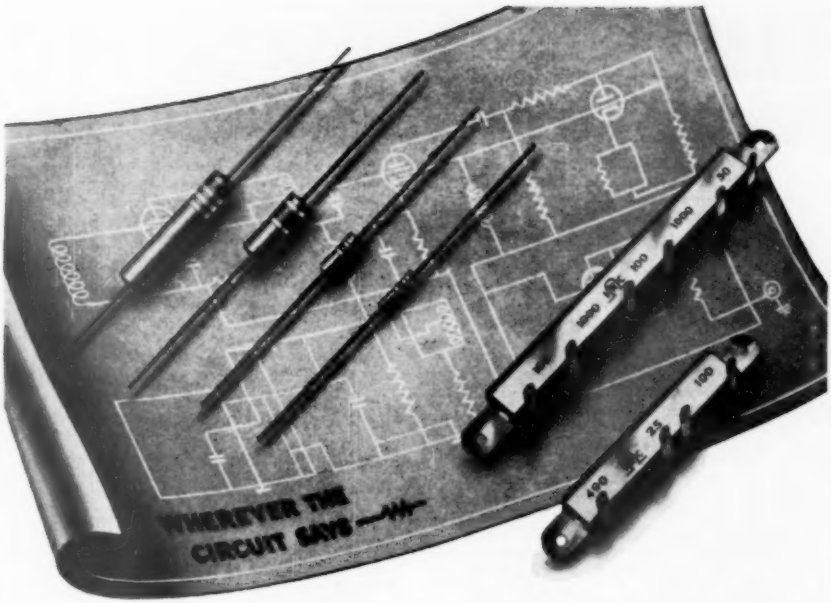

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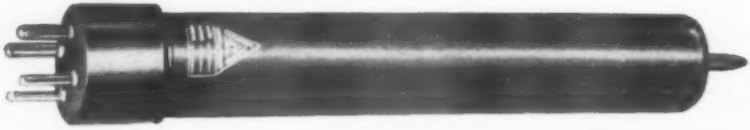

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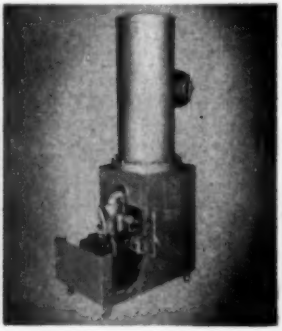

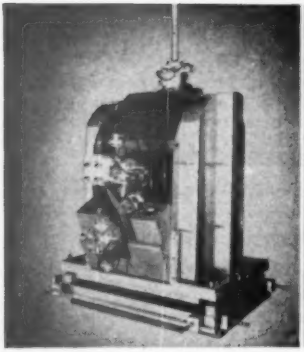

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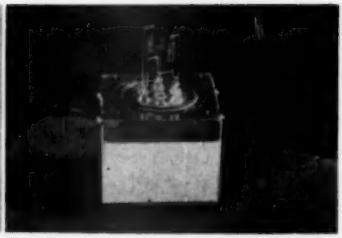

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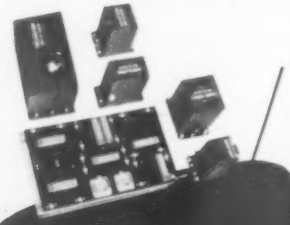

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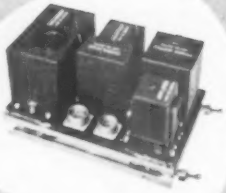

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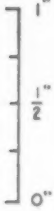

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Practical Aspects

of

Radioactivity Instruments

Introduction

Until now, information on the many *practical* aspects of radioactivity instruments has never been gathered in one place. On the basis of many requests from readers, the editors of NUCLEONICS felt that an introduction to the practical considerations involved in instrumentation would be useful.

The design and fabrication of radioactivity instruments has advanced considerably in the past few years. Not long ago the making of a single Geiger tube was an art. Now, although we are far from solving all of the problems connected with them, many companies mass-produce G-M tubes.

However, there is no question but that the nuclear instrumentation field is still in its infancy. This is reflected to a certain extent in the material that follows. The section on calibration, for example, does not by any means contain "the last word" on this subject. This is so primarily because much remains to be learned about calibration of certain types of instruments, especially neutron detectors.

Still something of an art is the construction of electronic devices. The techniques of construction are best learned by experience, and by careful observation of the workmanship of experienced technicians. And an understanding of the design and operation of a circuit can greatly facilitate intelligent construction; with this understanding one can not go far wrong in construction. But, for those who lack this experience and knowledge, there is a lack of collated, basic information, not only about construction, but about testing, servicing, and calibration.

We have thus asked the authors to provide a basic guide for the readers. Where possible, examples and solutions of problems have been given. References can be referred to for further information.

In general, design considerations have been omitted. They have only been included where necessary for an understanding of the text.

This report is divided into three sections:

1. Construction—W. C. Elmore, H. Kallman, and C. E. Mandeville—p. S-3
2. Testing and Servicing—W. J. Ladniak—p. S-13
3. Calibration—L. D. Marinelli—p. S-20

Because practical information on instrumentation is of very great interest, NUCLEONICS will publish more extensive articles on the various phases discussed here in future issues. —*The Editors*

Construction*

W. C. Elmore

H. Kallman

C. E. Mandeville

THERE ARE TWO WAYS in which construction of instruments may be discussed. One is to choose a particular "representative" instrument and describe its construction step by step. The other is to divorce design considerations as much as possible from the discussion and consider those construction practices which are applicable to broad areas of instrumentation. This latter course is limited because much of the information must be qualitative, but it has the advantage that the information so presented is more widely applicable.

This article follows the second course. To facilitate discussion, it is divided into two sections, circuits and detectors. These are further subdivided to delineate construction practices for types of instruments. Except where absolutely necessary, design is not considered.

CIRCUITS

Electronic circuits used in counting may be divided into two classes; high signal level and low signal level. Count rate meters and scalers fall in the first class; preamplifiers and amplifiers in the second.

The method of wiring and constructing a circuit depends both upon the signal level and upon the rise time of the signals. In general, the lower the signal level and the shorter the rise time the more critical the wiring becomes. In this article, components, chassis construction, and wiring are first discussed as they apply to all instruments, with differences between high- and low-level applications being pointed out. Then the special requirements of specific types of circuits are considered.

Components

A review of components has been presented previously (*1*). Since that review, a number of new components have been developed. Deposited carbon resistors, smaller electrolytic capacitors, and compact ceramic capacitors can aid construction, but are usually used in the same manner as before. Perhaps ceramic capacitors can replace micas in many applications, but manufacturers' specifications for temperature coefficients, voltage ratings, and loss characteristics at several megacycles should be checked.

Capacitors ordinarily should not be used in parallel to obtain the desired capacitance in a fast pulse circuit. The parallel capacitors may form an oscillating circuit, and can have a very high impedance at a particular frequency. If such a circuit were used as a bypass

* The information on circuit construction was contributed by Dr. W. C. Elmore, Department of Physics, Swarthmore College, Swarthmore, Pa.; on scintillation counters by Dr. H. Kallman, Department of Physics, New York University, New York, N. Y.; on Geiger counters by Dr. C. E. Mandeville, Bartol Research Foundation, Swarthmore, Pa. The information on ionization chambers was taken from the literature.

for high-frequency components of a transient, it would be shock-excited and oscillate. This behavior is particularly troublesome in pulse amplifiers. Where high-level pulses are used and their shape and amplitude is not of importance, the formation of an oscillating circuit may not be troublesome.

Tolerances. Use of at least 10% tolerance components in all circuits is recommended. Most circuits are critical enough that higher tolerance may affect operation. Often the circuit designer will specify components of lower tolerance. It usually does not pay to obtain 20% tolerance parts and expect to select those with closer tolerance since the manufacturer has already applied selection to obtain his 5 and 10% tolerance parts.

Selection of tubes. In the case of tubes used for the input stages of a preamplifier, it is best to test a number of tubes and select those that give the least noise. In most applications, however, no special selection of tubes is necessary. Artificial aging of electrometer tubes to reduce flicker-effect noise at low frequencies has been reported (page 12 of ref. *2*).

Line noise. Noise, causing spurious counts, can get into a circuit through the power line or by electromagnetic radiation. In high-level devices, this may not cause trouble. With amplifiers and other low-level devices, however, it is best to use transformers that have electrostatic shielding to isolate the equipment from the line. Line filters can be used, but they are usually not built into the equipment (*3*).

High-voltage transformers. High-voltage 60-cycle transformers that do not undergo corona breakdown (and thus give spurious pulses) are difficult to obtain. In construction of a proportional-counter or ionization-chamber circuit (or any other low-signal-level device), it would appear advisable to use a voltage doubling circuit to obtain the necessary high voltage.

In G-M counters, an r-f transformer is often used to supply high voltage. The transformer and the accompanying electronic circuit should be adequately shielded, with some provision for air flow to provide cooling. There is some danger that the r-f high-voltage circuit may interfere with the operation of a low-level detector, such as a pulse ionization chamber, located in the same laboratory.

Chassis Construction

It is desirable to have all laboratory instruments constructed for relay rack mounting, because grouping and interconnecting several pieces of apparatus for a given experiment is thereby simplified. If necessary, relay-rack instruments that are going to be used individually can be put in separate boxes, but there is no harm in setting an open relay-rack chassis on a table.

The simplest and easiest method of relay rack construction is to employ a conventional chassis with side brackets to support it. This style of construction does not lend itself to easy servicing if the chassis is one of several in a relay rack. Servicing can sometimes be facilitated by using the "bathtub" type of chassis—the underside of the chassis faces the relay rack panel, and the tubes project horizontally to the rear. In this case a section of the front panel can be made removable for servicing. This complicates construction because the space on the front panel for controls is limited, and the controls must in some way be connected to the circuit either before or after the chassis and panel are clamped together.

A file-drawer type of construction has many points in its favor. Individual chassis could then be pulled out, pro-

vided that the cables connecting the different equipment in the rack are of sufficient length. It is possible to fold up a chassis, leaving the sides open for servicing. This and other styles of chassis construction have been described previously (*1*). Good examples of various styles of construction can be found in commercial instruments.

Portable instruments. Two partly contradictory requirements must be met in portable instruments. The instrument must be rugged, but at the same time it must be light. Thus, the chassis should be kept to minimum size and subminiature components used where possible. Tube clamps and firm anchoring of components adds ruggedness.

Shock mounting of the chassis in portable survey instruments is ordinarily not necessary if the instruments are handled with reasonable care. The main purpose of shock mounting is to avoid microphonics caused by vibration during use, and the human body acts as a good shock absorber. Wiring should be rigid, however; this is discussed in more detail under count-rate meters.

It is good practice to enclose portable survey instruments in water-tight cases. Rubber or synthetic gaskets can be used to seal joints in the outer case.

Circuit Wiring

Circuits can be wired either point-to-point or with resistor mounting strips. Where only a single unit is being made, or where it is anticipated that changes may be made in the circuit after it has been constructed, point-to-point wiring appears to be the better method. Resistor mounting strips require considerable care in their layout, especially if individualized strips are made for a particular circuit. Their use appears to be worthwhile if a number of units of the same circuit will be built.

For the same reason, plug-in units are most useful in quantity production. They can be used to offer variations of a circuit within the same general instrument. For the individual constructing only one instrument, plug-in units have little to recommend them. They can facilitate servicing in a laboratory where a large number of units are in use.

Lengths of leads. In general, any leads that carry a signal should be kept short. In low-level stages, they should be kept short to avoid pickup of hum or extraneous transients. In any case, where one is dealing with fast signals, leads should be short to reduce stray capacitance, which will increase the rise time of the signal.

In laying out a circuit for fast operation, such as a pulse amplifier, one must bear in mind the Miller effect—the amplification of the capacitance between the grid and plate leads to a tube by an amount equivalent to the gain of the tube. Thus, plate and grid leads on the same tube should be as far apart as possible.

In a very fast amplifier or scaler, certain leads such as that from cathode to ground do not appear to carry a voltage signal, but do carry current. It is undesirable to have the cathode ground lead too long, since it has inductance and a current can generate a signal voltage. This is also true of the lead from the plate resistor to the plate decoupling capacitor.

This may not be important in the usual scaler where the induced signal is in millivolts and the signal in the scaler is in volts, but if an amplifier and scaler are built in the same chassis, the signal induced in or by a current-carrying lead in the scaler may induce signals in the amplifier.

Count-rate Meters

It is necessary to mount high-megohm resistors used in counting-rate circuits on good insulators. Bakelite and

other plastic insulators which tend to soak up moisture should be avoided. Usually surface leakage is more important than volume leakage. Glass insulators can be washed with alcohol and then coated with ceresin wax to reduce surface leakage caused by humidity; certain silicone compounds can also be used.

A charge can accumulate on insulators used to mount high-megohm resistors. If mechanical parts move, as in a vibrating-reed electrometer, or if a wire moves in the circuit, the field created by this charge can induce a spurious voltage signal. The charge and thus the induced voltage may drift with time and cause the zero of the instrument to change.

It is important, therefore, to shield the insulation electrostatically so that there will be no lines of electrical force between the charged insulator and the vibrating part. It is usually impossible to effect complete shielding. In all cases, wiring and construction should be as rigid as possible, to minimize the effects of vibration.

Mounting of electrometer tubes. Electrometer tubes are microphonic, and vibration of an electrometer tube may change the grid spacing and thus the zero. Therefore these tubes should be mounted with a rubber clamp or other shock-absorbing device. This is especially important in portable instruments.

Scalers

Diodes used to couple the stages of a binary scaler need not be matched, since they are essentially operating in an "on-off" fashion. If germanium diodes are used, however, it pays to test their back resistance with an ohmmeter and use only those with a high resistance. Good germanium diodes show a back resistance of about 1 megohm when measured with an ordinary ohmmeter; poor ones, a resistance as low as 100,000 ohms or less. Also, germanium diodes are temperature dependent, and should not be used where the temperature will be high. If used, they should be mounted away from resistors which may heat them. The resistors in series with the neon interpolation lights should be mounted near the tube socket to avoid adding stray capacitance to the plate circuits of the flip-flops.

Matching triodes and resistors. The accuracy with which tubes and resistors in a scaling circuit must be matched depends in part on the speed at which the scaler has been designed to operate. In a 5-μsec scaler, almost any triode of the type called for in the design is usually found satisfactory.

In constructing a scaler, it pays to match the resistors in the flip-flop circuits. It is usually not important that the resistors all have exactly the same value. Thus one can measure the groups of resistors called for and sort them into pairs of approximately equal value. These pairs are then used in symmetrical positions in the various flip-flops. An advantage of this pairing method is that it does not require more resistors than are used in the circuit.

There are plug-in scaling units available commercially. A small laboratory could simplify construction of a scaler by use of these units, but the characteristics of the instrument would be preset, and servicing, if only one scaler were built, would not be facilitated to any great extent.

Binary versus decade. Kuper has discussed the choice of binary or decade type of scaler (*4*). Binary scalers are inherently more stable and less critical because feed back is not employed. Thus they are easier to construct. A decade scaler does eliminate complicated interpolations and is easier to

use, but a binary scaler can be built to operate at higher speeds than those achieved with a decade scaler.

Preamplifiers and Amplifiers

To keep pulse rise time short in amplifier circuits, the stray capacitance of signal-carrying leads from the plate of one tube to the grid of the next must be minimized. In addition, choice of tubes can affect rise time; tubes with a high gain-bandwidth figure of merit should be used. This is, however, a matter of design, not construction.

Straight-line construction ordinarily should be adopted. That is, successive tubes in an amplifier should be placed, one after the other, from one end of the chassis to the other. Where space does not permit this style of construction, it is possible to fold the amplifier back on itself if a shield is used between the two sides. With this type of construction, it is unnecessary to shield each stage separately.

Where there is a chassis ground, it is advisable to have a local ground at each stage. Tube sockets with grounding rings are strongly recommended; they facilitate grounding locally at each tube. All ground leads should be soldered.

In a pulse amplifier, a ground bus for all stages, which is then connected to the chassis at only one point, is usually undesirable. In a preamplifier, this type of construction is sometimes used to minimize the pick-up of extraneous transients.

In most high-speed circuits, it is common practice to ground one side of the heater leads. Usually the circuit does not respond to 60-cycle and the hum problem is not important. However, grounding of one side of the heater can help shield the signal-carrying leads. For example, in the usual pentode, such as a 6AC7, the heater pins are 2 and 7, pin 8 is the plate, 1 is the ground, 3 is the suppressor (goes to ground or cathode potential), and 6 is the screen (bypassed to ground). By grounding pin 7 of the heater, the plate lead is surrounded by two grounded pins, effectively shielding the plate. In addition, the high side of the heater (pin 2) is surrounded by two grounded pins. This manner of connecting the heater aids in preventing oscillation in high-gain pulse amplifiers (by regenerative feedback through the heater leads).

In the case of miniature sockets, the central sleeve and the heater pin nearest the grid should be grounded.

Preamplifier coupling. Preamplifiers are usually mounted as near the detector as possible because the amplitude of the voltage signal is inversely proportional to the capacitance of the detector and of the leads. The noise in the circuit is set primarily by the shot effect in the first tube. Thus, to achieve a good signal-to-noise ratio, the capacitance should be kept as small as possible.

If design considerations make it necessary to separate the preamplifier from the detector in a low-level device, the capacitance of the connecting cable should be as low as possible. A home-made cable of brass pipe about an inch in diameter with a fine wire stretched down the middle can be used. Such a cable is sometimes used in reactors if it is undesirable to place the metal of the preamplifier in the high flux region where the detector is located. If there is voltage between the wire and the pipe, vibration can induce a signal, but this signal is in the audio range and can be attenuated by a pulse-shaping circuit in the amplifier.

Shielding of cables. The problem of shielding electronic apparatus has never been completely solved. Cables connecting detectors with associated circuits should be shielded, but a single layer of shielding is probably insufficient if the apparatus is used where bad elec-

tromagnetic disturbances occur, as in the vicinity of a cyclotron. The problem is aggravated because the cable is grounded at several points—at the detector, the amplifier, and the counting circuit.

Multiple shielding is a possible solution. That is, in addition to the usual shielding, a second shield would be used; this second shield would be grounded to the first at only one point. This type of shielding, however, is difficult to carry out in practice.

Another partial solution to the shielding problem is to raise the signal level, perhaps to a 1-volt level, before the signal is transmitted through a long cable, for instance, from a preamplifier to the main amplifier. Such a procedure complicates the design of the preamplifier, but should result in a decrease in the number of spurious counts caused by inadequate shielding.

DETECTORS

Most radiation detection today is carried out with one of four types of detectors: Geiger-Müller counters, proportional counters, scintillation counters, and ionization chambers. Because the construction of G-M and proportional counters is similar, they have been considered together. Since commercial photomultiplier tubes are usually used in scintillation counters, only construction external to that tube will be considered.

G-M and Proportional Counters

The most common type of G-M and proportional counter has a cylindrical cathode and a single wire anode supported within it. Either glass or metal is used to form the counter envelope, and conventional glass-blowing and metal-fabrication techniques are used. The most common metals used are copper, brass, and stainless steel. The parts of metal counters are usually soldered together, and nonacid flux is used to avoid eating away of the metal and contamination of the counter.

Where noncylindrical shapes are desired, glass can be pinched during blowing to form corners; metal parts can be cut and formed to the desired shape and soldered or brazed together.

The choice of metal or glass construction is governed to some extent by the application, but a metal counter is easier to fabricate since the envelope itself forms the cathode. However, as discussed later under outgassing, a glass counter may offer certain advantages.

Cathode construction. In a glass counter, the cathode can be formed by plating or evaporating metal on the interior of the glass envelope. Colloidal graphite coatings are sometimes used and are brushed or sprayed on. Although evaporation techniques can provide a cathode of uniform thickness, vacuum evaporation chambers are required for their deposition.

Perhaps the easiest way of providing a cathode in a glass-wall counter is to insert a sleeve of metal. Tubing of the desired diameter can be used, or metal plates or wire mesh can be formed over mandrels of the proper size. When cathodes are formed from solid plates, the seam can be soldered, brazed, or spot welded to provide solid construction. With mesh, a double fold is used to form the seam. Copper wire screen of 50–80 mesh is usually used. The lead to such a cathode is spot welded in place.

Copper is widely used in cathode construction because it is easy to fabricate. When a cathode surface other than copper is desired, it can be plated on the cathode. This plating method is particularly useful when a bismuth cathode is desired, since bismuth itself is brittle and hard to work (*5*, *6*).

Oxidized cathodes. Design considerations sometimes call for an oxidized

cathode surface (7). Oxidized surfaces are usually less photosensitive, but there have been cases where oxidation increased photosensitivity. To oxidize the cathode, air can be admitted to the counter while it is at high temperature during outgassing. Another method for cathode oxidation (2) is to heat the cathode in the presence of NO_2.

Anode wire. Tungsten is commonly used for the central wire of a counter (7). An empirical rule followed at Bartol Research Foundation limits the diameter of the central wire to 5 mils; 3-mil wires are usually used there. Some commercial end-window counters have 10-mil central wires, but it is difficult to construct a cylindrical counter with a central wire larger than 5 mils that will not break down in operation.

The central wire should be free of burrs or other protrusions that will cause a concentration of electric field. A simple method for smoothing out the wire is to pass an electric current through it, after assembling the counter, until it is heated to between red and white hot, and then allow it to cool. During heating, the wire will sag, but it will snap back to its original position when the current is turned off.

Mounting of anode wire. Various methods have been proposed for mounting the anode. In a glass counter, the simplest method is to use thicker wire as the end supports and hook or solder the anode wire to it. The supports run through the glass envelope, which is sealed vacuum-tight around the wire. In a metal counter, one end of the anode is fastened to a small rod which passes through an insulator in the metal cap; the other end is fastened to a glass hook or other insulating device which is attached to a wire run through the other cap and soft soldered vacuum tight in place at the point of exit.

For mounting the anode wire in metal-wall counters, insulators such as quartz, glass, porcelain, mica, Lucite, polystyrene, fluorothene, polyethylene, Teflon, Kel-F, and Kovar glass can be used (2, 8). They can be held in place by rubber or metal gaskets, solder seals, or wax.

Some method must be employed to keep the anode under tension during assembly. A simple method is to attach one of the support wires to a cord running over a pulley to weights.

Filling tubes. A filling tube can be either attached during glass blowing, or formed of a short length of copper tubing soldered into a hole in one end of a metal counter. This tube is used to connect the counter to the outgassing and filling systems.

Thin windows. Thin "bubble" windows can be formed by glass blowing, but it is difficult to make them reproducibly. Mica windows for insertion in end-window counters can be made more reproducibly. They can be held in place by several methods: by compression seals, by wax, by evaporating a thin metal coating on their perimeter and using glass-to-metal seals, or by using a low-temperature polymerizing fusion seal (7).

A metal grid can be used to support the window. This grid can also reduce the distortion of the counter field caused by the window. Another method used to reduce this distortion is to apply a thin external coating of colloidal graphite to the window.

Cleaning. Prior to assembly, the cathode and other counter parts should be cleaned and polished. Shiny copper cathodes are achieved by cleaning with dilute nitric acid. Sometimes an additional step, heating in the presence of hydrogen, is used. When a glass envelope is used, the cathode is dipped

into the acid prior to insertion in the envelope. After assembly, the counter is flushed out and allowed to dry. At Bartol, metal-cathode counters are washed with a 10% nitric acid, 10% sulfuric acid water solution; Aquadag-cathode counters are washed with pure water only.

Outgassing. The purpose of outgassing is to remove from the counter electronegative gases and other impurities which interfere with counter operation. A subtlety not often appreciated is that gases occluded in the metal parts of a counter can cause delays in counter action which lengthen the double coincidence resolving time of counters that are employed in coincidence counting, and the maximum double coincidence resolving time is thought to be about 1×10^{-6} sec. At Bartol, double coincidence resolving times of 3.5×10^{-8} sec have been achieved with G-M counters in coincidence without genuine coincidence loss; this is attributed to the use of glass-envelope counters which have been properly outgassed. It appears impossible to outgas all-metal counters to this extent because of the greater occlusion of electronegative gases and because temperatures higher than the melting point of the solder or other sealing compound cannot be used in outgassing (*7*).

Outgassing is accomplished by vacuum pumping the assembled counter at forepump pressures (10^{-3} mm Hg) for several hours, at the same time heating the counter to about 400° C in an oven. The counter should be allowed to cool before being removed from vacuum.

Filling. The filling gas is chosen on a design basis and will not be discussed. A filling gas reservoir, gas purifiers, the counter to be filled, a pressure-measuring device, and a vacuum pumping system are connected to a common line. The entire filling system thus formed is vacuum pumped, and the filling gas is then allowed to enter the system. Sometimes the counter is flushed with the filling gas prior to actual filling (*9*).

After the desired gas pressures have been achieved, the filling tube is sealed off. Glass counters are sealed by heating the filling tube, pinching it shut, and drawing it out and snipping it off; metal filling tubes are pinched shut, clipped off, and then sealed with soft solder.

Scintillation Counters

Many problems result from the limitations of the photomultiplier tubes themselves. The most important one is making the signal-to-noise ratio as large as possible. Some of the limitations can be compensated for by means external to the tube, especially by coupling the scintillator to the photomultiplier efficiently and obtaining a suitable signal-to-noise ratio.

Optical coupling. The ideal situation is to have intimate contact between the crystal and the photomultiplier tube envelope. Scintillation crystals have high indexes of refraction—about 1.7 and more—and if an air space exists between the crystal and the tube, internal reflection in the crystal prevents much of the light from reaching the tube. Solid crystals which emit in the visible can be cemented to the tube with Canada balsam or Duco cement. When a 1P21 tube, with the photosensitive cathode at the curved side of the tube, is used, the crystal can sometimes be shaped to fit the tube exactly. With a 5819 tube, with the cathode at the end, the crystal can be flat and can be mounted on the end of the tube.

With liquid scintillators, the top of the tube envelope itself can be used as a part of the container for the liquid. This allows the desired intimate contact.

Where it is necessary to use a crystal that is larger than the cathode, a

truncated cone of Lucite or quartz can be cemented between the crystal and the tube.

Light guides. Sometimes it is necessary to mount the crystal at some distance from the photomultiplier. In this case, a Lucite tube can be used to guide the light to the photomultiplier. Tubing with a higher index of refraction would make a better light guide, but it is hard to obtain. An important feature of substances serving as efficient light guides is an extremely low absorption coefficient for the light transmitted since the light travels a considerably large distance through the light guide. Other light guides such as oil-filled brass rods with polished internal walls have been used in the past, but it is felt that Lucite performs better (*10*).

Dark current and tube noise. The background of the tube is caused by thermal emission of electrons from the sensitive layers in the photomultipliers and can be reduced to some extent by cooling the tube with dry ice. Cooling with liquid air will reduce it to a minimum. Sometimes it is not possible to use external cooling. The noise depends, to some extent, on the type of the photosensitive layer; layers more photosensitive to the red give more noise pulses.

The signal-to-noise ratio associated with photomultipliers can be influenced to some extent by external electromagnetic fields (*11*). The 5819 tube has a metallic coating on the inside of the envelope, but this does not screen out external fields completely. It has been found that electrostatic shielding will increase the signal-to-noise ratio. The greatest improvement has been obtained by applying the cathode potential to the external shield. For the 5819 tube, magnetic shielding is also recommended.

Since extraneous light must also be prevented from reaching the cathode of the photomultiplier, the same shield can be used for both light and electromagnetic shielding.

Photosensitive counters. Mandeville has described a method for producing Geiger counters which are extremely photosensitive in the ultra-violet regions (*12*). The same problems of crystal mounting obtain as with photomultipliers. In addition, the cement used for mounting must transmit in the ultraviolet region.

Ionization Chambers

Ionization chambers have been constructed with a variety of metallic and nonmetallic walls, and in many configurations. Tissue-equivalent walls have been made with gelatin and plastic. Where nonconducting electrode material is used, a colloidal graphite (Aquadag) conducting coating can be applied.

Since the ionization chamber is essentially a low-signal-level device, care should be taken to avoid microphonics, especially when an amplifier with a long pulse-clipping time is used. This dictates rigid construction; lead electrodes have been used to provide additional rigidity. Sometimes use of a screen electrode in place of a solid plate or making electrode spacing as large as possible will aid reduction of microphonics (*2*).

Insulators such as quartz, glass, porcelain, mica, Lucite, polystyrene, fluorothene, polyethylene, Teflon, and Kel-F are used to support high-voltage electrodes (*2*). Kovar glass has been widely used. Insulator volume should be minimized to avoid production of strains during evacuation (*13*). These strains produce stray currents during operation. Where high humidity conditions occur, it may be necessary to coat glass insulators with ceresin wax to reduce surface leakage.

To prevent electric shock to the

operator, chambers have been coated on the outside with an insulating plastic. Sprayed-on Krylon gave good results (*14*).

The choice of filling gas and its pressure is dictated by the use and design of the chamber. If distortion of pulse shape is not permissible because of design considerations, electronegative gases such as O_2 and Cl_2 should be avoided; they distort the pulse by electron attachment (*2*). The electron attachment coefficient should also be considered in choosing polyatomic filling gases.

A thin window is sometimes used where it is desired to detect low-energy, nonpenetrating particles. Thin Zapon film is widely used for this purpose (*15*). The film is usually supported on a wire grid, and because the film is broken easily, the grid must be carefully fabricated so that no burrs or sharp protrusions remain to puncture the film.

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Testing and Servicing

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MUCH TIME is expended by the design engineer in creating the circuit for a radiation instrument. The best techniques known to him are used by the instrument mechanic in fabricating the circuit. But if the instrument is not properly tested and serviced, optimum performance will not be obtained.

The primary purpose of testing an instrument is to determine whether it lives up to its specifications; servicing, of course, is done to keep it operating. In addition, testing and servicing provide data which aid the development of future equipment by pointing up the shortcomings of present equipment.

This article gives some of the techniques used to test and service instruments, and presents a method used at Oak Ridge to correlate design, testing, and servicing.

TESTING

All instruments should be tested very thoroughly after they are constructed. Proper testing of the instrument before it reaches the user will prevent much trouble and will sell the user on the reliability and dependability of the instrument.

Equipment

To test an instrument properly, sound testing equipment is needed. The most important piece of equipment is a pulse generator that provides a choice of positive or negative output pulses. The positive pulse should be variable from 20 volts to 0.2 mv in amplitude from a 500-ohm output impedance. With an external 75-ohm attenuator, negative output pulses from 1 volt to 10 μv should be available.

The output pulses should have a fast rise time, a flat top, and an exponential decay. Two basic pulses should be provided with characteristics as follows:

	Long pulse (μsec)	*Short pulse* (μsec)
Rise time	0.03–0.08	0.02–0.06
Pulse width	200	60
Exponential decay	200	50

The pulse generator should provide repetition rates, in addition to line frequency, of 1 cycle, 200 cycles, and 1 kilocycle, within $\pm 10\%$.

This type of pulse generator can be used for testing and servicing scalers, amplifiers, and count-rate meters. A special pulse generator may be needed for special-purpose linear amplifiers.

In addition to the pulse generator, other test equipment is made necessary by the characteristics of the instruments being tested. The majority of monitoring and survey instruments are portable, and are powered by batteries. Good meters are needed for checking

battery voltage under proper conditions.

Many monitoring and survey instruments contain electrometer tubes. These tubes should be properly aged; when two or more are required in a circuit, they should be matched under the conditions in which they will be used in the circuit. As a result, there is a need for a good electrometer-tube ager.

Because these instruments measure very small currents, high-value resistors are used. These resistors should be checked accurately. For this, a high-megohm bridge is needed which will measure resistances as high as 10^{13} ohms with about 1% accuracy.

In many monitoring and survey instruments, the background noise is sufficient to make accurate measurement difficult. It has been found that this is due largely to insulator noise. Therefore, means should be available to reduce this noise.

Many survey instruments are used for checking air contamination; dust samples are collected on filter paper. To facilitate collection of the same representative sample at all times, a setup for testing the proper flow of air across a filter paper is needed.

Auxiliary equipment such as good oscilloscopes, vacuum-tube volt-ohmmeters, and attenuator boxes are also needed for proper testing.

Data Sheet for Preamplifier

Serial No._____

Rise and Fall Time

Band width	*Rise time*	*Fall time*
2 Mc	____	____
200 kc	____	____
20 kc	____	____

Signal-to-Noise Ratio

	cps
2 Mc	
Noise counts at____volts	____
Signal large	____
Signal at_____db	____
200 kc	*cps*
Noise counts at____volts	____
Signal large	____
Signal at_____db	____
20 kc	*cps*
Noise counts at____volts	____
Signal large	____
Signal at_____db	____

This preamplifier was tested with Linear Amplifier Serial No._____

Tested by: _____

Date: _____

Procedures

The construction of all instruments should be tested to see if they meet required standards. Soldered connections should be tested visually and physically. Physically, a good pull on the wire with a pair of long-nosed pliers should be used. Many connections may only be held with solidified rosin that is present in the solder. This type of soldered joint will cause trouble after the instrument has been moved around a few times. Solidified rosin should be removed with alcohol or acetone from all joints to prevent corrosion.

The wiring of the instrument should be checked to see if it agrees with the approved sketch. All resistors and capacitors should be checked to see if they are of the proper value and rating. They should be observed closely to see that the tails have not been pulled away from the body of the components. Many times, especially on resistors, the tails of the resistor are soldered so tightly to the lugs of tube sockets or resistor board that a tune can be played as you run your fingers over them.

If the tails of resistors are very short,

Data Sheet for Linear Amplifier

Serial No._____

Gain and Rise and Fall Time

Pulser		*Linear amplifier settings*				*'Scope observations*	
Range (mv)	*Dial (div)*	*Coarse*	*Fine*	*Band width (Mc)*	*Output (Volts)*	*Rise time (μsec)*	*Fall time (μsec)*
10	—	64	1	2	50		
10	—	64	1	0.5	50		
10	—	64	1	0.1	50		
30	—	8	1	2	50	—	—
30	—	8	1	0.5	50	—	—
30	—	8	1	0.1	50	—	—

Linearity and Noise

Pulse-height selector (divisions)	*Signal (mv)*	*Pulse-height selector (divisions)*	*Signal (mv)*
100	—	40	—
90	—	30	—
80	—	20	—
70	—	10	—
60	—	—	—
50	—		

Peak noise: __ divisions

Tested by: _____

Date: _____

the resistance value should be checked very closely. Short resistor tails may cause unsatisfactory performance.

It has been noticed that the value of carbon resistors is sometimes changed considerably by the heat of soldering. The change is in the positive direction, i.e., the resistance increases. The resistance changes are smaller in 1-watt resistors than in ½-watt resistors. Such resistance changes are greater and more frequent in higher resistors.

Performance. The performance of an instrument should be checked very thoroughly. In many cases, data sheets giving the test results should be made up and sent to the user of the instrument. Two instruments requiring such data sheets are linear amplifiers and the preamplifiers used with them; examples of these sheets are shown on this page and can serve as guides in testing.

Other instruments usually need no data sheets, but thorough testing is still necessary. For example, the following procedure is used in testing a scaler. This procedure is representative of the type of testing which should

be carried out on all instruments before they are used.

Testing performance of Higinbotham scaler.

1. Check high-voltage supply.

a. Check high-voltage meter calibration, using standard voltmeter.

b. Minimum 600–700 volts. Maximum 1,400–1,600 volts.

c. Test voltage regulation. A line variation of 100 to 115 volts should change the high-voltage output less than 0.5 volt at 1,200 volts. A regulation of 0.003% change per % change of line voltage is desirable.

2. Check B+ supply.

a. Minimum 275 volts, maximum 400 volts.

b. Check for stability. Voltage should not fluctuate.

3. Check input stage.

Maximum sensitivity of the input stage should be at least 0.1 volt. To check this, use a pulse generator and set the output of the pulse generator to a negative 0.1-volt pulse. The width of the pulse should be 10 μsec or less. Feed this negative 0.1-volt pulse into the G-M tube connector on the front panel.

CAUTION: Turn off the high voltage before feeding the pulse.

Adjust the cathode bias of the input stage to where it will just trigger on the 0.1-volt pulse. To make this adjustment, use an oscilloscope with a 50 μf capacitor into the input. The number of pulses observed on the 'scope at this point should be the same as the number of pulses fed into the input. The output out of the input stage should be enough to trip the first scaling stage. Increase the input pulse to −5 volts and check that operation is not affected by changing the input pulse from −0.1 to −5.0 volts.

4. Check scaling stages.

a. Set a common cathode bias on 6SN7 tube.

b. Maintain a constant negative 3-volt pulse on the input. Check all scaling stages. This is done with the use of an oscilloscope. If not scaling properly, remove 6SN7 tube from socket and measure the potential difference between the grid and the cathode. This bias should be +1 to +12 volts. To adjust this, change the common cathode bias.

c. When scaling stages are working properly, insert a variable transformer in the power line to check scaling operation under varying line voltages. Vary the input voltage from 95 to 125 volts. Make the changes in line voltage slowly and rapidly, to see if this will throw the scaling stages off. If any scaling stage will not scale properly under this test, then the stage is probably out of balance and must be corrected.

5. Check output stage.

a. To check the output stage, plug in a Wizard recorder and measure the voltage drop across it when the coils are energized. This voltage should be 175–230 volts.

b. Check to see that the output of the scaler comes from the proper plate of the last scaling stages. This can be done by watching the interpolation light of the last scaling stage and at the same time observing when the recorder advances a number. The recorder should advance when the interpolation goes out.

6. Check operation with a known frequency source.

a. Use a 60-cycle or 120-cycle pulse generator and run a ten-minute count on the scaler. This will show up any error in the performance of the scaler.

b. Slow the pulse generator down low enough so that a visual check of the interpolation lights is possible.

7. *Check operation with a glass G-M tube.*
   a. Remove pulse generator and hook up a glass G-M tube to the scaler.
   b. Set high voltage to operating voltage for the G-M tube. Use the standard source and run a four-minute count to check the scaler.

SERVICING

The servicing of instruments follows a given procedure at ORNL. This procedure is based on past experience with instrument faults and their causes; it changes as improvements are made on the instruments. Many of the servicing procedures follow the methods outlined under testing. Additional tables of procedure are appended here for monitoring and survey instruments; these can serve as a guide in setting up procedures for other instruments.

1____

Instrument: G-M counter survey instrument (Walkie-Talkie)

Use: (1) Indicate presence of beta or gamma radiation by audio signal.

Service problem	Causes
Voltage is up but no audio signal	1. Bad G-M tube.
No background at all	1. Burned out electronic tube.
High background outside radiation field.	1. Low batteries. 2. Bad tube. 3. Contaminated instrument.
Intermittent operation	1. Bad cable connections.

2____

Instrument: Ionization-chamber beta-gamma portable count-rate meter (Cutie Pie)

Use: (1) Measure within 10% hard gamma radiation between 5 mr/hr and 10 r/hr.
(2) Measure current due to soft gamma or beta radiation.

Service problem	Causes
Will not zero	1. 7½-volt batteries not same voltage. 2. Resistors on both sides of potentiometer not balanced. 3. 22½-volt battery down. 4. Filament battery down. 5. High-value resistor bad. 6. Tube base dirty. 7. Dirty insulator.
Needle fluctuates or reads below zero	1. Insulator dusty or dirty. 2. Bad connection. 3. High-value resistor open. 4. Resistor dirty. 5. Tube burned out. 6. Battery getting low.
Reads off scale	1. Stud mounting on ionization chamber grounded to case. 2. Corroded or dirty connection. 3. Bad resistor. 4. Bad switch.
Meter reading but no radiation	1. Contamination of instrument. 2. Light seeping into ionization chamber. 3. Bad meter.
Meter reading less than radiation	1. Instrument grounded incorrectly. 2. Meter needle sticks.

3____

Instrument: Ionization-chamber alpha-beta-gamma portable count-rate meter (Zuess)

Use: (1) Measure hard gamma radiation between 5 mr/hr and 2 r/hr.
(2) Measure current due to soft gamma or beta with window open.
(3) Measure current due to alpha radiation with both windows open.

Service problem	Causes
Will not zero	1. Battery is down. 2. Dirty resistor. 3. Dusty switch deck. 4. Contaminated instrument.
Needle fluctuates	1. Open high-value resistor. 2. Dirty insulator.
Reads off scale	1. Tube burned out. 2. Battery shorted.
Reading less than known radiation	1. Bad tubes. 2. Battery low.

4____

Instrument: Ionization-chamber charge collector and reader (Lauritsen Electroscope)

Use: (1) Measure within less than 1% hard gamma radiation between the intensities of less than 1 mr/hr and 1,000 mr/hr.
(2) Measure ionization current due to beta radiation.

Service problem	Causes
Scale is dark	1. Battery is dead. 2. Bulb burned out.
Will not zero	1. Battery is weak. 2. Plating flaked off fiber.
Fiber drifts	1. Dirty insulator. 2. Dirty fiber. 3. Instrument contaminated.
Scale blurred	1. Lens not properly focussed. 2. Dirty lens.
Fiber off vertically	1. Scale has moved in electoscope. 2. Arm holding fiber may have slipped.

CORRELATION

For testing and servicing to be effective, records should be kept of all operations and results. These records guide the design engineer in selecting proper components and layout for his circuit, aid the instrument mechanic in determining what improvements can be made in fabrication, and provide the user and serviceman with test results indicating the instrument's capabilities.

At Oak Ridge National Laboratory, the record system described in the following paragraphs is used. It is supplemented by personal contact between the design engineer, the instrument mechanic, and the testing and servicing divisions. Smaller laboratories require the same basic system, but a simpler version may be used.

Testing. A card is used to record the results of tests performed on new instruments. Listed on the card are the instrument name, drawing number, model number, fabrication, name of person who tested the instrument, and results of tests on soldering, wiring, and performance. This card provides data for the design engineer and the instrument mechanic, and forms part of the testing department's records.

In addition, certain instruments, such

Summary of Instrument Failures

The records discussed on these pages are used at Oak Ridge National Laboratory to provide information on the causes of instrument failure. Typical of the information gained is this breakdown of causes of instrument failure, taken from data for a three month period in 1950.

Type of failure and services	*Per cent of total number of failures*
Transformers replaced	0.79
G-M tubes replaced	9.69
Filter capacitors replaced	2.91
By-pass capacitors replaced	1.88
Resistors replaced	2.39
Vacuum tubes replaced	25.35
Instruments calibrated	3.65
Miscellaneous failures	53.42

as preamplifiers and linear amplifiers, are provided with performance data sheets which give the information required in use and servicing of the instruments.

Servicing. It cannot be overemphasized that contact between the servicing group and the design, construction, and testing groups should be maintained. Often the servicemen can improve testing procedures and design.

To maintain contact between the groups at ORNL, all servicing is recorded on instrument repair orders. On the left side of an $8 \times 4\frac{1}{2}$-in. sheet, the information which will identify the instrument being serviced—instrument numbers, building and room in which it is used, who to contact, and who picked up the instrument—is recorded. The right side is divided into two sections—service required and repairs made. This space is used to record data on problems encountered in servicing the instrument. Space is provided at the bottom of the form for the date when service was completed and for the serviceman's signature.

After servicing is completed, this form is sent to a central location where the information on it is compiled for future reference. At this central location, an $8 \times 4\frac{1}{4}$-in. card is kept for each instrument in the laboratory. Each instrument is identified by name, model, type, range, where it is used, and what it is used for. Columns are provided for date of servicing, service required, and the serviceman's name.

Once a month the data is collected from these forms, distributed, and analyzed. Thus contact between the various groups is maintained.

Calibration

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THE CALIBRATION of a radiation detection instrument consists of comparing the readings on its scale to those of a standard instrument, under experimental conditions which allow the latter to measure the radiation in accepted units. It should be noted that in general the conditions under which standardization is possible may not be similar to those under which the detection instrument is used.

In the field of nucleonics the purposes underlying standardization of radiation instruments are many, and the ranges to be covered are indeed enormous. Thus, calibration of survey and personnel instruments (ionization chambers, counters, and photographic emulsions) may involve dose rates of the order of milliroentgens per day, whereas the calibration of the output of some experimental X-ray tube may involve rates as high as millions of rep (roentgen-equivalent-physical) per second.

As to the choice of units, the situation is rendered complex by both the physical nature of the many primary ionizing agents in use (such as alpha, beta or gamma rays, neutrons, etc.) and by the physical state and location of the sources, such as roentgen-ray machines, nuclear reactors, and radioisotopes in solid, liquid, or gaseous phase that in turn may be external or internal to the biological system under investigation.

It is not surprising, therefore, that no single instrument is suited to all conditions of radiation exposure, nor is the accurate correlation between biological result and physical measurement always feasible.

The radiological physicist, confronted by these complexities and pressed by the need of a radiation unit of wide significance, seems to have reverted, after a period of dismay, to the primitive state and is considering at present the adoption of a unit of radiation dose based explicitly on the energy gained per unit mass of the irradiated medium. At the Sixth International Congress of Radiology (London, July 1950), the erg per gram was made the official unit of dose for all ionizing radiations (*1*).*

Although this unit has the priceless merit of unambiguity, it is difficult to realize it directly under many experimental conditions. Pending more exhaustive investigations, this unit at present shares unofficial acceptance with a unit based on ionization which remains identical with the roentgen for photons and the rep for alpha and beta rays.

At the present time neutron radiation is measured in terms of particle or energy flux or in terms of dose, the unit for the latter being the energy unit of Gray (93 ergs/gm) (*2*). In what follows, it is proposed to survey the field

* It should be noted that the biological effect depends, in general, on other factors besides the amount of energy absorbed by the biological system. The most obvious are fractionation, dose rate, and specific ionization (ions/cm) resulting from the exposure.

of radiation-detector calibration and to present some comments on the actual state of the art.

PHOTONS

The roentgen is defined as the quantity of X- or gamma radiation such that the associated corpuscular emission per 0.001293 gm of air produces, in air, ions carrying 1 esu of electricity of either sign. This unit bears the following relationship (Fig. 1) to the energy flux

$$\text{roentgens} = K\mu F n_0$$

where F = energy flux in erg/cm²; $K = 9.25$; $n_0 = 3.88 \times 10^{20}$, the number of electrons in 1 cm³ of air at NTP; and $\mu = \sigma_a + \tau + \sigma_p$, σ_a being the Compton true absorption coefficient, τ the photoelectric-absorption coefficient, and σ_p the pair-formation-absorption coefficient, all referred to one "air" electron.

It is obvious that if we divide the ordinates of Fig. 1 by the corresponding abscissae and plot the result against photon energy, we obtain the photon flux per roentgen as shown in Fig. 2.

As to source of photons, Table 1 lists some conveniently available radioelements which emit gamma radiation within the range 140–2,300 kev. A more expensive, but eminently flexible, source would be an X-ray tube with a Be window capable of operation between a few kev and a few Mev.

Ionization Chambers

Photon radiation can be determined in roentgens by measuring the ionization produced by the corpuscular emission associated with a known air mass.

The choice of air as the basic medium in measurements of photon radiation is based on the fact that, for equal radiation exposure, the ratio of the energy absorbed per gram of air to the energy absorbed per gram of most biological substances does not vary appreciably with the energy of the photon (*3, 4*).

With photons of energy as high as a

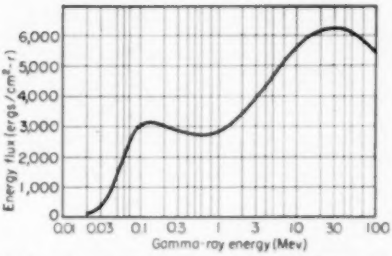

FIG. 1. Gamma-ray energy flux per roentgen as a function of energy (*50*)

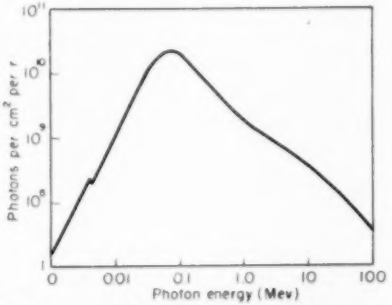

FIG. 2. Photon flux per roentgen as a function of energy

TABLE 1
Gamma-Ray Sources in the Range 140–2,300 kev

Isotope	*Method of production*	*Half-life*	*Energy (Mev)*
Ce^{141}	Uranium fission	30.6 d	0.14
Hg^{203}	(n, γ)	43.5 d	0.28
Cr^{51}	(n, γ)	26.5 d	0.32–0.27
Au^{198}	(n, γ)	2.7 d	0.411
Cs^{137}	Uranium fission	33 y	0.67
Co^{60}	(n, γ)	5.3 y	1.1–1.3
K^{42}	(n, γ)	12.4 h	1.51
$Sb^{124}+Pb$	(n, γ)	60 d	1.7
$Na^{24}+Pb$	(n, γ)	14.8 h	2.3

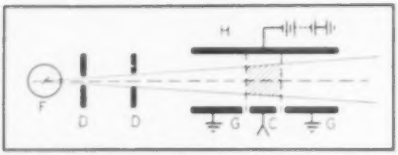

FIG. 3. Parallel-plate ionization chamber

few hundred kilovolts, radiation can be measured satisfactorily by using a small source, such as the focus of a commercial X-ray tube, and a standard air ionization chamber of practical dimensions. In this instrument, X-rays generated by the source are first collimated by a diaphragm system and then passed through adequately spaced plane electrodes.

A schematic drawing of such a chamber is shown in Fig. 3. The drawing is out of proportion so that essential features can be emphasized. The source of the X-rays is indicated by *F* and the diaphragm system by *D*. The three parts of the electrode system are: *C*, the ion-collector connected to a current measuring device; the guard plates, *G*; and *H*, the flat plate connected to the battery. A properly designed shield acts to support the assembly and to eliminate extraneous radiation. The shaded portion is the region from which ions are collected.

To express the readings of this chamber in roentgens, it is essential to know accurately the temperature, pressure, and volume of the air from which the ions are collected, and to establish equilibrium between photons and electrons.

Whereas the cross section of the beam is known from the area of the limiting diaphragm, the height of the significant volume is set by the length of *C*, if the lines of force between the electrodes are perpendicular to its surface. This in turn implies that (a) the guard plates be coplanar and sufficiently close to the collecting electrode, (b) that *G* and *C* be at the same potential during measurement, and (c) that all electrostatic influence of the shield at *C* be eliminated within the collecting volume by use of guard plates of proper length or by the possible addition of guard wires (*5*, *6*). Photon-electron equilibrium is obtained by making the distance between limiting diaphragm and collecting plate equal to, or longer than, the range of the most energetic electron liberated by the X-ray in use,

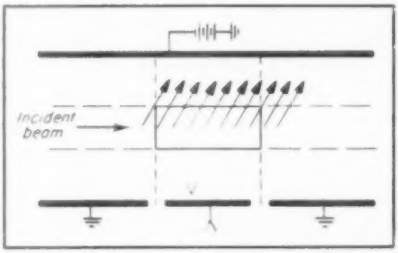

FIG. 4. Ion collection in a standard ionization chamber

and by separating the electrodes beyond the range of any electron generated by the beam. Sufficient voltage between *H* and the system *GC* must be applied to obtain saturation.

Under these conditions the equivalent of the total ionization produced by the corpuscular radiation associated with the collecting volume is collected by the system. This is schematically shown in Fig. 4 where the arrows represent secondary electrons generated in the air of the chamber. It is obvious that the ionization produced outside the *collecting* volume by the associated corpuscular radiation in the *significant* volume, *V*, is compensated by the ionization produced by the corpuscular radiation originating outside the collecting volume. There is no such compensation when the photons are of such low energy that appreciable absorption takes place within the volume of the chamber, but in this case it is possible, by slightly modified design and by

proper experimentation, to account fully for this phenomenon (*7*).

As the energy of the photons increases, the standard air ionization chamber method presents certain difficulties which can be fully appreciated only by studying the literature in this field. For example, it is difficult to design a diaphragm which accurately delimits the beam, and it becomes very expensive to construct a free-air chamber of dimensions adequate to insure full compensation of associated electrons and collection of all ions produced by them. In the region of energies between a few tenths to a few Mev, measurements of photon radiation in roentgens can best be realized by means of the so-called air-wall chamber method.

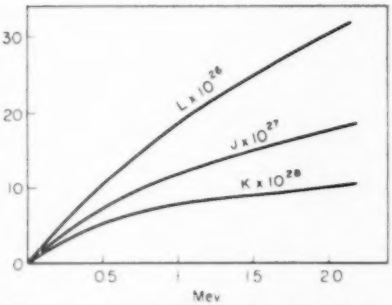

FIG. 5. Functions *J*, *K*, and *L* for correction of ionization readings of air-equivalent chambers

This chamber derives its name from what it tries to accomplish; namely, to surround a definite mass of air with material which will interact with both primary and corpuscular radiation as a solid layer of air would.

Under these conditions photon-electron equilibrium is established in a much smaller space than that required by the standard air chamber. As a result of exhaustive analysis available in the literature (*8*), it has been found that, to act as a standard, the air-wall chamber should contain a known volume of air and have walls of known chemical composition, comprising elements of atomic number close to 7.

In addition, (a) the linear dimension of the ionized volume should be small in comparison with the range in free air of the ionizing particles, (b) the walls of the chamber should not unduly attenuate the primary radiation but should be thick enough so that further increase in the thickness does not change the number of ions collected in the air volume, and (*c*) the distance between source and chamber should be large in comparison with the linear dimensions of the latter.

When these requirements are met the result in roentgens can be found by dividing the esu/cm³ of air at normal temperature and pressure by a correction factor, B, of the form

$$B = 1 + (2J/L)(\log Z_w/Z_a) + (4K/L)(\log Z_w/Z_a)^2$$

where Z_w and Z_a are, respectively, the atomic number of the wall and of air, and J, K, and L are functions of the primary photon energy and of the energy loss undergone by the corpuscular radiation in air. Graphs of these functions are shown in Fig. 5, as calculated by Laurence (*9*) for monochro-

TABLE 2
Factors for Correction to Air-Equivalent Thimble Chambers

Chamber material	*Correction factor*
Sulfur	1.21
Aluminum	1.08
Carbon	0.98
Cellulose	0.97
Protein materials or pure bakelite	0.96
Commercial bakelite	0.96–0.97
Amber	0.93
Paraffin wax	0.92

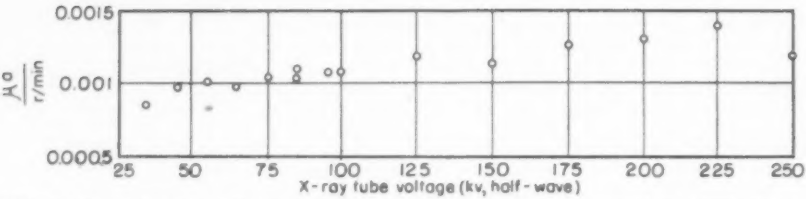

FIG. 6. Dependence on X-ray tube voltage of luminescence current of polyvinyl carbazole per roentgen per minute

matic radiations. As an indication of the magnitudes involved, Table 2 lists the correction factors pertaining to thimble chambers of various materials when used with radium gamma rays (*8*).

From the foregoing, it is obvious that the calibration of instruments in this region consists essentially in comparing them to an air-wall chamber. No basic difficulties are involved except that the range of ionization currents is apt to be so large that intermediate secondary standards may be necessary.

Usually photon detectors based on the measurement of ionization in air confined by walls of low atomic number can be made to conform with most of the physical requirements of the air-wall chamber; hence this type of apparatus has the advantage of retaining reasonable proportionality with the accepted standard throughout a wide range of photon energy. F. H. Day of the National Bureau of Standards has calibrated beta-gamma ionization chambers by exposure to X-rays. His results show satisfactory proportionality with the standard air chamber in the range 100–1,200 kv peak photon energy (*13*).

Scintillation Counters

Proportionality with the accepted standard is also shown by scintillation counters using crystals containing elements of low atomic number, such as anthracene or naphthalene. Since these counters have the desirable characteristics of high intrinsic sensitivity and enormous range, they are attracting the attention of many radiological physicists.

Figures 6 and 7 show the relationship between response of two scintillation counters (using organic crystals) and roentgens as measured by air-wall thimble chambers throughout a wide energy range (*10, 11*). On the basis of these preliminary results there exists some hope of using scintillation counters as primary standards if, in addition to sound engineering development, basic information connecting energy loss in the crystal and light emission is obtained. The discovery of solutions adaptable to scintillation counting has widened the prospects of applicability of this device.

G-M Counters

Another widely used radiation detector is the G-M counter. It can be calibrated for use with photons like any other instrument; i.e., by comparison with the standard air chamber or air-wall chamber. As a dosimeter, its general usefulness is limited to the high energy region, since its envelope is usually not air equivalent, and to low radiation levels because of the dead time of its discharges. However, on account of its sensitivity, special use has been made of it in X-ray and gamma-ray spectroscopy. Its efficiency, whether expressed in counts per incident quantum or counts per roentgen, is in general dependent on the atomic number of the wall and on the photon energy. Figure 8 shows the idealized relative efficiencies

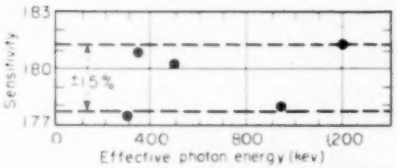

FIG. 7. Energy dependence of naphthalene with 931-A tube. Sensitivity is ratio of tube current to chamber reading

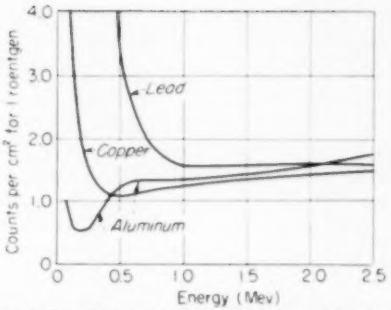

FIG. 8. Theoretical counts per cm² for 1 r in lead, copper, and aluminum counters

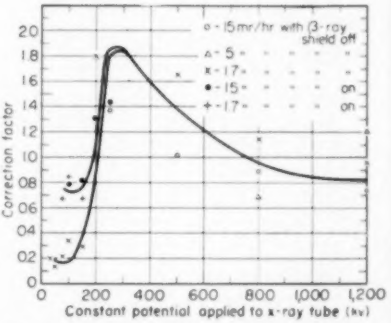

FIG. 9. Response of a G-M counter to filtered X-radiation

in counts/cm² per roentgen with counters of high and low atomic number as a function of photon energy (*12*). Experiments performed with a copper counter exposed to monochromatic radiations agree with the theory (*12*).

When the radiation is not monochromatic, the efficiency, or correction factor, must be found by experimental means. An example of such a correction factor is shown in Fig. 9 for filtered radiation from an X-ray tube. It is obvious from the evidence presented that the wavelength dependence of G-M counters is rather marked below 800 kv, especially if the radiation is heterogenous. Among the remedies proposed to ameliorate this situation, the adoption of special alloys in the construction of the walls seems the most practical for the time being. It remains to be seen whether this can be accomplished without unduly distorting the axial sensitivity of the instrument.

Photographic Emulsions

Last but not least of the practical radiation detectors is the photographic emulsion which owes its popularity in certain phases of nucleonics to its versatility, availability, and inexpensiveness. Since the reading to be correlated with radiation units is the blackening of the emulsion, special care must be taken that the latter is not influenced by development or differences in sensitivity of the emulsion. This is usually done by exposing representative samples of a batch of films to known amounts of radiations corresponding to the range to be measured. After the batch and the samples are developed together, the samples can provide a graphical relationship between blackening density and radiation exposure from which the exposure of the rest of the batch can be deduced. This method presupposes that, aside from the radiations to be measured, the two sets of films are given identical treatment as to temperature, humidity, light, and all the many factors which, besides radiation, are apt to influence film blackening. It is evident, therefore, that in film work a great deal of care is necessary to obtain reliable results; this is not prohibitive in practice.

Photographic emulsions in a general

sense can be viewed as ionization chambers permitting the recording of ionizing events in solids by revealing the affected grains upon development. The behavior of grains, however, is somewhat more complex than the behavior of gaseous ions. Extensive investigation of the behavior of photographic emulsions exposed to photons has revealed that the sensitivity is a complex function of the photon energy. Figure 10 shows the relationship of typical film blackening for different X-ray exposures as a function of tube voltage (*14*). It will be seen that for equal density, radiation emitted by an X-ray tube at 100 kv is about six times as effective on this type of film as the radiation emitted at 1,400 kv.

The reasons for this are many: the effective atomic number of a film emulsion is quite different from the effective atomic number of air, and hence the ratio of the energy absorbed per unit mass in the two media does not remain constant for all photon energies; other factors that seem to influence the response are the relation of grain size to the length of the track of the secondary electron, and the intrinsic sensitivity of the grain to the specific ionization along the track. In reviewing some recent work done along these lines both here and abroad, one comes to the conclusion that in the high energy range, the validity of the experimental results quoted is vitiated by the fact that in many instances the experimenters have neglected to provide photon-electron equilibrium in the emulsion under investigation, although computation of the energy absorbed therein presupposes it implicitly.

In some applications of film dosimetry with photons of high energy, the emulsion must be shielded from electrons generated in air and in the surroundings, if any significance is to be given to work of this kind. The striking variation of emulsion blackening with gamma rays of different energy can be modified with judiciously chosen screens placed on both sides of a double coated film. A 1-mm Cd screen extends the region of practical proportionality between roentgens and density from over an Mev down to about 200 kev (*14*); this is, however, accomplished at the cost of practically eliminating the response to radiations below 100 kev.

The need of better film packs for this purpose is therefore apparent.

It may be well to recall that the calibration of a radiation detection instrument requires the use of an X-ray or gamma-ray beam which is homogeneous throughout the area occupied by the instrument, and that verification of the inverse-square law is necessary before it is finally adopted as a matter of routine. It is also necessary to ascertain that no extraneous scattered radiation affects either the standard or the instrument under test. Finally, since the radiation instrument to be calibrated may often be used where radiation is produced by several arbitrarily located primary or secondary sources, it is well to determine its response as a function of direction.

ALPHA and BETA PARTICLES

In contrast to the calibration of gamma-radiation instruments, for which units and instruments standards are provided, the standardization of alpha- and beta-radiation instruments is as yet to be accomplished in a universally accepted manner. The problem of experimentally determining either the flux of particulate energy impinging on a surface or the energy loss in a given mass is relatively simple in theory.

An ideal standardization setup could consist, for example, of a source of suitable monoenergetic particles, such as a Van de Graaff generator of He ions or electrons, yielding uniform flux over an area sufficiently large to encompass the radiation detector to be standardized.

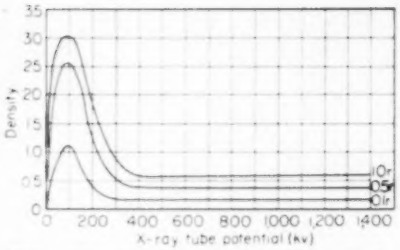

FIG. 10. Emulsion blackening of du Pont packet type 552 films as a function of X-ray tube potential

It is obvious to workers familiar with this subject that this expensive setup would be of limited use because the fields available today are sufficient at best to cover only minute instruments, such as the crystals of scintillation counters. Wider fields have been produced with the betatron (*15*) at relatively high energies, but no detailed information has been published which could aid in the evaluation of the betatron as a practical source of beta rays for the calibration of most types of radiation detectors.

Despite the lack of an ideal source of monoenergetic particles, much useful information, and in many cases all that is necessary, can be obtained by calibrating detection instruments with standard beta or alpha sources practically identical in all respects to the sources of radiation to be explored.

If the source of radiation is one of the many radioelements in use today, the problem of standardization becomes one of ascertaining the disintegration rate of the reference source. This can be accomplished in several ways:

1. By calorimetric measurements of the total particulate energy emitted by the source (*16*). Once this is known, it is a simple matter to determine the number of particles if their average energy is either available in, or calculable from, the literature (*17*).

2. In vacuum, the loss of charge of an isolated source can be used to find the absolute disintegration rate (*18*).

3. It is possible, by the use of the gamma-beta coincidence methods, to measure the absolute disintegration rate of several radioelements (*19*).

4. By the use of a thin-walled G-M counter and suitably standardized sources (such as RaDEF), it is possible to arrive at a fair estimate of the beta emissivity of several isotopes (*20*, *21*).

5. By the use of the so-called 4π method, as yet not thoroughly described in the literature, it is possible to assess the particulate emission of many sources with a minimum number of instrumental corrections. (*22*).

Advantages and limitations of each method have been amply discussed and reported in the literature (*22*, *23*).

Extrapolation Chamber

The measurement of particulate radiation dose in rep presents unusual difficulties. In biological objects of dimensions large compared to the particle range, and in which radioelements are uniformly distributed, the dose can be calculated on the basis of concentration of the radioelement and the average energy per disintegration. Under these favorable conditions, or on surfaces where the same conditions obtain, the use of the extrapolation chamber is indicated as a standard. This chamber, originally proposed by Failla (*24*), is schematically shown in Fig. 11. It consists of a volume of air, usually cylindrical in shape, limited in its height, S, by the inner surfaces of two plane electrodes, and of cross section equal to that of the collecting electrode,

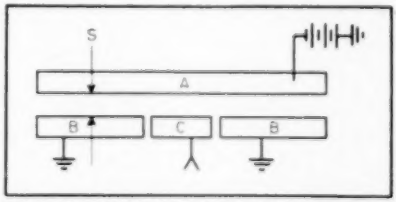

FIG. 11. Failla's extrapolation chamber

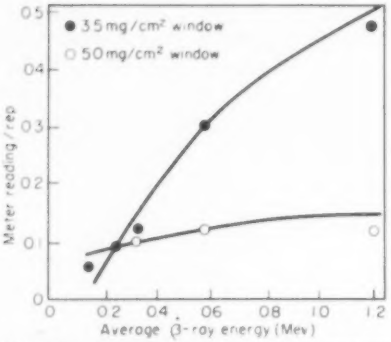

FIG. 12. Response of two G-M counters to different beta-ray energies

C, which is coplanar with the annular guard ring, B. By extrapolating to zero the thickness of the upper electrode, A, and the spacing, S, it is possible to obtain the number of ions, I_a, per unit mass of air at the surface of the collecting electrode. Hence it is relatively simple to assess the dose D_c in rep at the surface of the material of the collecting electrode by the formula

$$D_c = KI_aW \times 1.72 \times 10^{-14}$$

where K is the ratio of the mass stopping power of the particles in C to the stopping power in air, and W is the average energy in ev necessary to form a pair of ions in air. The correctness of these assumptions has been confirmed by using collecting electrodes containing known concentrations of radioelements (*27*). In fact this method, when convenient, can be used to standardize beta- or alpha-ray emitters (*22*). Very recently a study of the response of G-M survey instruments to beta rays has been made by use of the extrapolation chamber (*25*).

The precautions about scattering, which have been noted in the section on photons, become more onerous and stringent in the case of beta or cathode rays. For this type of radiation, care should also be taken to assess what disturbance in the radiation field is caused by the instrument itself, and to what extent its response is influenced by the direction of the incoming radiation. In practice, it would be well to visualize collimated beta radiation as a fast stream of water capable of splashing for considerable distances in a most disheartening fashion.

Ionization Chambers

In general, instruments of the ionization-chamber type would be expected to follow the dose in rep more closely than counters would; the latter, on account of the practical requirement of relatively strong and leakproof walls, may show considerable variation in response to beams of particles of widely different energies. Figure 12 shows the experimental results reported by Tochilin *et al.* (*25*) for two G-M counters of different window thicknesses.

Photographic Emulsions

The response of photographic emulsions to ionizing particles has been reported sporadically in the physical literature, mostly as an adjunct of efforts to evaluate beta-ray spectra in spectrometers using the emulsion as a detector. A typical response studied by Baker (*26*) for a limited range of monoenergetic electrons is shown in Fig. 13; Eastman lantern-slide plates with a standard density of 0.24 were used. In practice, photographic evaluation of personnel exposure to beta radiation has proved difficult, and, al-

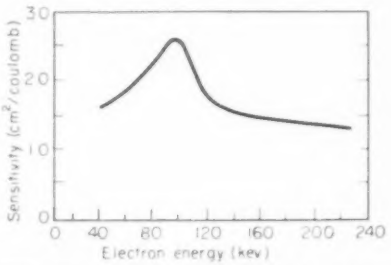

FIG. 13. Emulsion sensitivity to monoenergetic electrons as a function of energy

though efforts have not been spared to correct the situation, no widely accepted method has been proposed as yet.

As a detector of alpha radiation, the photographic emulsion has found, so far, no application in health physics.

NEUTRONS

The calibration of neutron-detecting instruments is still in its initial stages. This statement is self-evident if one considers that in the recent report announcing the construction of two Ra-γ-Be neutron sources to be used as national standards (*28*), the relative emission of these sources was stated to a high degree of accuracy, but no estimate was made of the error in absolute value.

The factors responsible for this state of affairs are many, but the most important are inherent in the nature of the neutron itself which—as it becomes a teen-age youth—is still expensive to produce, rebellious to control, and difficult to fathom.

It is not entirely out of place, however, to estimate—rather crudely to be sure—the average requirements of a laboratory capable of standardizing neutron detectors on the basis of present knowledge and of developing further acceptable procedures of standardization.

As to personnel, physicists thoroughly versed in experimental neutron physics would be essential, of course. However, they should also have the rare aptitude of instilling the wisdom acquired in physics laboratories during the last two decades into an undertaking which is intrinsically both exacting and unspectacular.

As to choice of sources, some rough estimates will be necessary. It will be assumed that in view of health-protection requirements (*29*, *30*), detectors to be calibrated will be required to measure, to within $\pm 10\%$, fluxes of the order of 10 $n/cm^2/sec$ (fast neutrons) and 100 $n/cm^2/sec$ (resonance or thermal neutrons).

To investigate the response of such instruments as a function of neutron energy in the thermal region, some monochromatization will be required; it will be assumed that this can be done acceptably with a reduction of total neutron fluxes of the order of ten at all energies. Therefore, if the apparatus needed for thermalization, collimation, and monochromatization have linear dimensions of the order of one meter, thermal fluxes of the order of 10^3 $n/cm^2/sec$ must be available at that distance. This entails sources emitting over 10^8 n/sec, namely a Ra-α-Be source of the order of 10 curies (*31*). The collimation will reduce scatter, and hence reduce the size of the laboratory.

As to fast neutron fluxes, the distance requirements can be reduced by a factor of ten, perhaps, if photoneutrons (acceptably monoenergetic) are used. In that case, fluxes of 10 $n/cm^2/sec$ at 30 cm could be obtained with sources of the order 1–20 curies (*32*). A laboratory thus equipped, however, would be limited to operations with maximal energies of 1 Mev and would be faced with the task of renewing the major part of its gamma emitters at frequent intervals since the sources are short-lived.

It is probable, then, that as a fast neutron source, an ion accelerator of the Van de Graaff type, capable of energies up to 5 Mev with adequate ion current, would prove to be the most versatile and the most economic installation. This apparatus, to produce monoenergetic neutrons in the 5 kev to 15 Mev range (*33*), would require a considerable array of accessories, such as provisions for the rapid change of targets, and special platforms for the placement of both standard and reference instruments at different angles from the ion beam.

A low-power reactor such as a "water boiler" might be considered as a better

TABLE 3
Instruments and Techniques for Neutron Measurements

Energy range	*Quantitative instruments*	*Energy-measurement techniques*
0.01–100 ev	BF^3 counters (*35, 36*) Activation of foils (*35*)	Mechanical spectrometer (*34, 37*) Crystal spectrometer (*34, 37*) Time-of-flight velocity selector (*34, 37*)
0.1–10 kev	Activation of foils (*35*)	Time-of-flight velocity selector (*37*)
1 kev–1 Mev	Long counter (*38, 39*)	Time-of-flight velocity selector (*37*) Energy of recoils (*40, 41, 42*)
>1 Mev	Long counter (*38, 39*) Recoil counters (*40, 41*)	Energy of recoils (*40, 41, 42*) Threshold detectors (*43*)

source of thermal and slow neutrons since its higher flux (*34*) would allow a greater degree of monochromatization of its beams and it could be converted very simply (*34*) into a source of fairly pure fast neutrons. It remains to be seen, however, whether the available energy range is adequate for the broader purposes of instrument calibration.

As to instrument standards, the hypothetical laboratory would require at least those which have proved reliable in the various range of neutron energies. These have been discussed in the pages of this journal (*35*); they are recorded here in Table 3, together with those references in which their merits and limitations are fully evaluated.

Despite the apparent variety of the instruments and techniques listed, the basic principles upon which the basic measurements of flux and energy depend are rather simple. Absolute measurements of energy can be made in the region below 10 kev only, since it is there that they may be obtained from direct measurements on velocity. In the higher ranges, since the estimates depend on the energy of recoils (mostly hydrogen), the estimates cannot be better than the proton energy measurement.

As to flux, all techniques seem to take advantage of the property of slowing down the neutron in a medium, to a velocity where the probability of its being captured in the detector is high. The remaining task consists of measuring the products resulting from its capture. These measurements entail absolute measurements of alphas (boron disintegration), betas (radioactivation of foils), or gammas (n,γ reaction).

Obviously, correction for the probability that the neutron escapes detection must be made. This means that the response of the standard instrument must be calculable from known or determinable cross sections. The latter is established in an absolute sense only by strict accounting of the transmission of monoenergetic neutrons in a detector foil in terms of the sum of all nuclear events occurring in the detector. A compilation of present knowledge of neutron cross sections is given in *ref. 44*.

Neutron Dosimetry

As a consequence of studies on the biological action of neutrons, neutron dosimetry has followed rapidly in the wake of the advances in neutron physics. The pioneer work of Aebersold focused attention early on the fact that the roentgen was of limited value in radiobiology and that, in particular, measurements of ionization in air-wall

chambers would be difficult to translate in terms of energy absorbed by the biological systems. Attempts to measure neutron dose (strictly, energy absorbed) became possible as neutron interactions became better known and as the first monochromatic sources of neutrons became available.

Paced by the earlier work of Gray on the properties of the "air cavity" in a photon flux, Zimmer (*45*) and Gray and Read (*46*) attempted the first determinations of neutron dose by ionization measurements in chambers of various wall materials and gas fillings, and by estimating therefrom the energy absorbed in each element of a more or less idealized biological system. Their computation was feasible and their methods consistent because the neutron source was essentially monochromatic.

The extension of this method to the measurement of doses in the presence of heterochromatic beams has been discussed at length by Gray (*49*), and by Rossi and Failla (*47*). It is to be concluded from their studies that satisfactory dosimetry can be established by measurements of ionization in chambers whose wall and gas filling are composed of chemical elements identical both in nature and in proportion to those present in the biological system under investigation. This equivalence must be interpreted in a very strict sense since only then can the energy absorbed per unit volume of wall be calculated as

$$\sum_k a_k = I W_k \rho$$

where $a_k = f_k F \bar{E}_k \sigma_k$ ergs/cm³, in which: f_k = fractional density of element k in the system, F = neutron flux (n/cm²), σ_k = collision cross section for element k, $\bar{E}_k$ = average energy transferred per collision to nucleus of element k, W_k = average energy (erg/coulomb) spent by recoil of atom k in the production of an ion pair in the chamber gas, ρ = relative density of wall to gas, and I = ionization of the gas in coulomb/cm³.

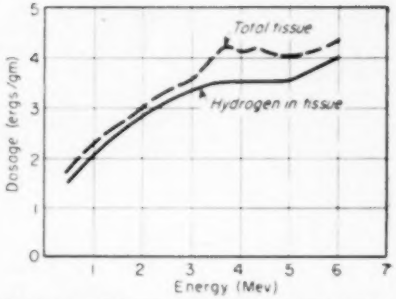

FIG. 14. Energy absorption in an idealized tissue for a flux of 10^7 neutrons/cm².

The dosage, D, is obtained by dividing the energy absorbed per unit volume by the density. The values of D for an idealized tissue ($C_4H_{40}O_{18}N$) exposed to a flux of 10^7 n/cm² is shown in Fig. 14* as a function of neutron energy.

As matters stand today—except for uncertainty in the value of W_k for recoils of different masses and energies—the tissue-equivalent chamber can be regarded as an acceptable standard for "pure" neutron sources of wide energy spectrum. In the presence of mixed sources of photons and neutrons, such chambers would always indicate the correct total energy absorption.

In health-physics laboratories, however, the energy contributed by each component must be known, since it is assumed that the radiological effectiveness of neutron radiation is ten times that of gamma or X-radiation. A distinction between the two requires the use of instruments practically insensitive to one component. By suitable design, Hurst and Ritchie (*48*) have constructed a proportional counter essentially sensitive to neutrons only. The counting rate of this counter, following exposure to unit flux, follows rather closely the shape of the curve in Fig. 14. If such an instrument were

* Courtesy of Dr. H. H. Rossi.

compared to the tissue ionization chamber in "pure" neutron fluxes, the relationship between counting rate and dose rate should be fairly independent of neutron energy. Hence a scaling factor would enable the observer to convert the counter reading to neutron dose.

In the presence of mixed photon and neutron radiation, a good evaluation of the hazard could be obtained from reading both the ionization chamber and the counter. This ideal situation, however, exists only with collimated beams because, unlike the ionization chamber, the counter has no isotropic response in its present form.

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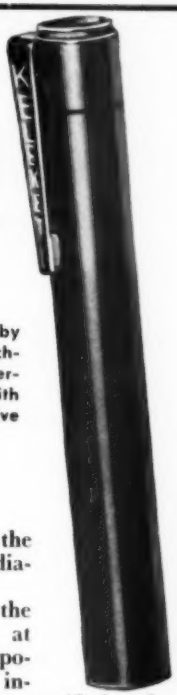

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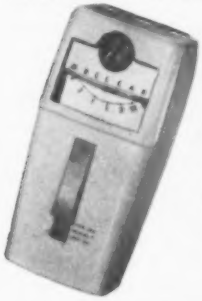

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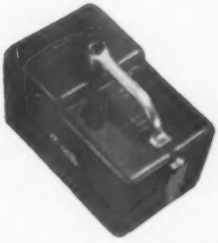

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